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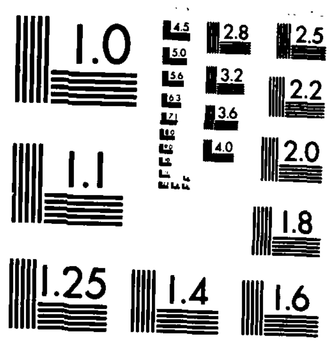

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Report No. CG-N-1-85

LORAN-C HARBOR AND HARBOR ENTRANCE SURVEY
CHARLESTON, SOUTH CAROLINA

R.L. GAZLAY

February 1985

Final Report

Prepared by
U.S. Department of Transportation
United States Coast Guard
Office of Navigation
Washington, D.C. 20593

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16. Abstract

LORAN-C is being investigated as a possible aid to navigation in Harbor and Harbor Entrance (HHE) areas, as outlined in the 1982 Federal Radionavigation Plan. LORAN-C can be used in the repeatable mode for excellent repeatable accuracies using waypoints whose LORAN-C time difference (TD) values have been previously measured. The exact accuracy achievable in a given harbor area depends on many factors and is best determined by measurement. If the true geodetic position is measured with an independent reference positioning system in addition to measuring the LORAN-C TDs, one can use the resulting TDs in the repeatable mode to achieve geodetic accuracies better than ±80 meters in many areas. Responding to a U.S. Navy request, we measured LORAN-C TDs simultaneously with Miniranger III, Raydist, and GPS positions along two routes in the Charleston, SC area. The results show that LORAN-C can provide ±29 meters geodetic accuracy along the Charleston river route and the ocean route to 20 miles offshore when using surveyed waypoints in the repeatable mode. The accuracy achieved beyond 20 miles was ±36 meters due to using a less accurate reference positioning system for surveying that area.

17. Key Words LORAN-C, Miniranger, GPS, Raydist, Harbor and Harbor Entrance, accuracy, waypoint, navigation.	18. Distribution Statement Document is available to the U.S. public through National Technical Information Service, Springfield, VA 22161

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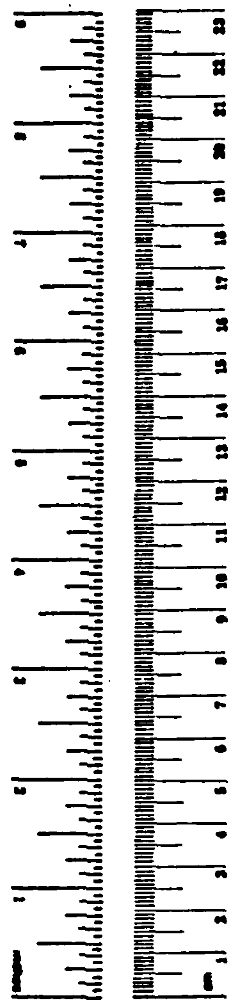
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

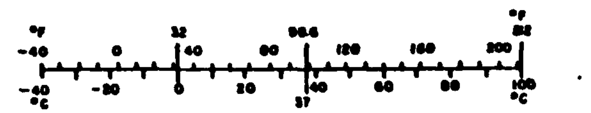
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION.

This report presents the results of a Loran-C Harbor and Harbor Entrance (HHE) Survey of the Charleston, SC area conducted by the U.S. Coast Guard Office of Navigation during April-July 1983.

1.1 BACKGROUND

Loran-C is a one quarter nautical mile geodetic accuracy system when used in its normal mode. Basically this means reading the Loran-C time difference (TD) readings on a Loran-C receiver, and plotting them on a nautical chart that has Loran-C lines of position (LOPs) printed on it to determine the vessel's position. The accuracy achievable in the normal mode depends heavily on how accurately the LOPs are printed on the chart, i.e. whether the LOPs are predicted with a salt water earth model, or are corrected for either predicted or measured Additional Secondary Phase Factors (ASFs). Even with the best corrections, Loran-C in its normal mode may only yield one quarter mile accuracies, although in many places it may be much better. One quarter mile accuracy is not good enough for navigating in HHE areas.

The accuracy of Loran-C in the repeatable mode is much better than in the normal mode. Repeatable accuracy refers to how well the system can be used to return to a particular point over and over again, without necessarily knowing the geodetic coordinates (i.e. latitude/longitude) of that point. For example, suppose we measure the Loran-C TD readings at the end of a pier, and then depart the area. At a later time we wish to return to the same pier using Loran-C. We maneuver until our Loran-C receiver reads the same TD readings as we previously measured. The distance we are from the end of the pier is a measure of the Loran-C accuracy in the repeatable mode. Note that in this example the geodetic position of the pier was not determined by our measurements. We could, however, determine the geodetic coordinates of the position independently using a more accurate reference positioning system. The point would be called a waypoint, and the process of determining the geodetic coordinates, together with measuring the Loran-C TDs is called surveying. If we had done this in the above example, then the distance we were from the end of the pier would also be a measure of the geodetic accuracy achieved in the repeatable mode when using the surveyed waypoint.

The Coast Guard is required by reference 1 to provide Loran-C coverage with an accuracy of one quarter mile 95% of the time in the U.S. coastal area, which is defined as 50 miles off shore, or to the 100 fathom curve, whichever is greater. However, there are several areas, notably the Texas coast south of Galveston, along the North coast of

Alaska, and in parts of the Hawaiian Islands where one quarter mile accuracy may not be provided by Loran-C in the normal mode. This happens because of poor signal strength, poor geometry, interference, poor ASF values, and other factors. Loran-C in the repeatable mode is also affected by all these factors except for poor ASF values. Using the repeatable mode sidesteps the ASF problem because the ASF factor is inherently measured and contained in the surveyed TDs. Still, the repeatable accuracy varies from one area to the next because of the other factors.

Loran-C is being investigated as a possible aid to navigation in HHE areas, as outlined in reference 1. The use of Loran-C in a given HHE area depends on defining the navigational requirements for the area, determining the accuracy that Loran-C can provide in that area and, if necessary, measuring the Loran-C TDs at known points for use in the repeatable mode.

The purpose of the Charleston HHE survey was to accomplish these objectives in the Charleston, SC area.

1.2 REQUEST FOR SURVEY

The US Navy Commander Mine Warfare Command, Charleston, SC contacted the Coast Guard Office of Navigation and asked if Loran-C could be used as a precision aid to navigation in the Charleston area for mine warfare. We estimated an accuracy of 30 - 40 meters could be achieved using Loran-C in the repeatable mode, but an HHE survey would be required to determine the actual accuracy. The Navy concluded that accuracies of ± 100 feet would be beneficial in mine warfare.

Meetings followed this initial contact which resulted in an Interagency Agreement between the Coast Guard and the Navy.

2.0 PROJECT REQUIREMENTS

2.1 INTERAGENCY AGREEMENT

Appendix A contains the Interagency Agreement which defined the roles and responsibilities of the Coast Guard and the Navy for this project.

Briefly, the Coast Guard was responsible for determining the Loran-C repeatable accuracy in two distinct areas of Charleston. The Ocean Route is a trackline beginning in the vicinity of the Charleston Seabuoy and extending seaward to a depth of 100 fathoms, a distance of approximately 52 nautical miles. The exact locations of the turnpoints (herein called waypoints) in the Ocean Route were specified by the Navy. The River Route is a trackline beginning near Buoy 62 near the Charleston Navy Base ordinance reach and ending at the Charleston Seabuoy. Waypoints on the River Route were defined as the turnpoints of the established channel centerlines.

2.2 DELIVERABLES

Outlined in the Interagency Agreement are the following Coast Guard deliverables from this project:

a. Waypoint positions in State Plane coordinates (South Carolina South), Latitude/longitude (NAD-27 datum and spheroid), Loran-C time difference (TD) readings, and Raydist lane counts (red/green).

b. Comparison plots between Miniranger, Loran-C, Raydist, and NAVSTAR GPS data.

3.0 DEFINITIONS, CONVENTIONS, AND METHODS

3.1 DEFINITIONS

The following definitions of terms will be used throughout this report.

Accuracy - The accuracy of an estimated or measured position at a given time is the degree of statistical measure of conformity of that measurement with the vessel's true position. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system must include a statement concerning the probability level of the estimate or measurement. Historically, navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will exceed a certain amount. A thorough consideration of errors is complicated by the fact that the total error consists of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the sensing and processing equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, human errors are usually excluded. See definitions for Geodetic Accuracy and Repeatable Accuracy.

GDOP - Geometric Dilution of Precision. All geometric factors that degrade the accuracy of position fixes obtained from a navigation system.

Geodetic Accuracy - (Also called Predictable or Absolute Accuracy) The accuracy of a position with respect to the geographic or geodetic coordinates of the earth.

HC - Horizontal Control.

HHE - Harbor and Harbor Entrance.

NAD-27 - North American Datum, based on the Fisher 1927 spheroid. A geocentric reference system that approximates the shape and size of the earth for a best fit in and around North America.

PILOT - Precision Intracoastal Loran Translocator. A computer based display terminal that compares real time Loran-C TDs to surveyed waypoints and displays navigation position information, both in chartlet and alphanumeric form.

Repeatable Accuracy - The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

TD - Time Difference.

Trackpoint - A Waypoint defined on the straight part of a trackline rather than at a turnpoint.

Two drms - Two drms is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place. The probability of 2 drms varies between approximately 95.5 percent and 98.2 percent depending on the eccentricity of the error ellipse. Two drms is usually considered a 95 percent probability minimum, and will be so used in this report.

Waypoint - A point along an intended track where a turn will occur. Waypoints are usually defined as the turnpoints on the centerlines of shipping channels.

WGS-72 - World Geodetic System (datum) 1972. A geocentric reference system that approximates the shape and size of the earth.

3.2 CONVENTIONS

The following conventions are used in this report.

Accuracy - All statements of accuracy are in plus or minus meters and 2 drms (95% confidence) unless otherwise stated.

Geodetic Positions - All geodetic positions are expressed in WGS-72 coordinates unless otherwise stated.

Mathematical Constants

WGS-72 Semi-major axis: 6378135.0 meters
Semi-minor axis: 6356750.5 meters
Flattening: 1/298.26

NAD-27 Semi-major axis: 6378206.4 meters
Semi-minor axis: 6356583.8 meters
Flattening: 1/294.9786982

Transformation Parameters:	X = - 20 meters
(NAD-27 to WGS-72)	Y = +156 meters
(Reverse sign for WGS-72 to NAD-27)	Z = +177 meters

Note: Transformation parameters were extracted from reference 7, figures 6, 7, and 8.

whole lane count while the vessel is within a 1/2 lane width of a known position. In Charleston, the lane widths on the Raydist baselines are approximately 48 meters wide, and they become wider towards the far limits of the coverage area. This means that to re-initialize after a whole lane slip, the position of the vessel must be independently known to an accuracy of ± 24 meters near the baselines and less accurately at the limits of Raydist coverage.

Re-initializing depends on the fact that nothing has disturbed the Raydist receiver's count of fractional lanes. If the fractional lane count is disturbed for any reason, then a new initialization must be done.

Thus, the operational accuracy of the Raydist system depends on how accurately the initialization point is known. For example, if the initialization is done at a point near Fort Sumter (in an area of near-optimum GDOP) whose position is known to an accuracy of, say, ± 20 meters, then the operational accuracy we could get thereafter with Raydist is:

$$\sqrt{20^2 + 8^2} = 22 \text{ meters near Fort Sumter,}$$

$$\sqrt{20^2 + 70^2} = 73 \text{ meters near the 100 fathom curve.}$$

6.9 HORIZONTAL CONTROL SITES

The Miniranger reference stations must be located at sites (called Horizontal Control or HC sites) whose positions are known to a high degree of accuracy.

Candidate HC sites were identified using topographical maps, HC description sheets, and US Army Corps of Engineers dredging charts and survey information. The criteria for site selection are:

- Line-of-sight visibility between the HC site and the survey area.

- Minimum 30 degree crossing angles from pairs of HC sites at all points along the survey route.

- Accessibility by land (vehicle/foot) or water (small boat or rubber boat).

- Probability of HC station recovery.

and so it was not used for any GPS position determinations. Four-satellite fixes were available for about 3 1/2 hours per day, while three-satellite fixes were available for about 4 hours per day.

Predictions by the Office of Research and Development indicated that we should expect a GPS accuracy on the order of ± 20 meters for a four-satellite fix, and ± 30 meters for a three-satellite fix, both 95% of the time in the entire Charleston area while satellites were visible. This predictrrion was based on a complex GPS system model and on previous tests. Approximately 90% of our GPS data was collected using four satellites.

6.8 RAYDIST

We had no experience with Raydist prior to the survey, so we had a Navy representative install and operate the Raydist equipment during the survey.

We tried to determine the accuracy we should expect for Raydist. Various Raydist documents and claims indicates that the "Raydist accuracy" is between ± 3 and ± 5 meters, depending on the source document or person. We used ± 4 meters. We were not able to get a clear definition from Raydist representatives on two separate occasions of the probability value (e.g. two sigma, 95%) associated with the ± 4 meters Raydist accuracy, or whether it includes the GDOP factor. We believe it is one sigma value (68%) and that it does not take GDOP into account.

In order to compare the accuracies of various positioning systems, we must state them in common terms. We express accuracy as two sigma (95%) and include the worst GDOP factor for the area of concern. We multiplied the stated ± 4 meter, one sigma figure by two to get ± 8 meters, two sigma (95%). Next, we predicted the GDOP in various areas where we expected to operate on the Ocean Route and found that it ranged from 1.11 near the shore to 8.74 at the furthest point of interest from shore. This means that the accuracy would degrade to 8 x 8.74 = 70 meters (minimum) at the furthest point. Achieving this accuracy depends critically on the accuracy of the initialization point, and therefore the Raydist accuracy would degrade further as the accuracy of the initialization point diminished.

When Raydist is first used, it must be "initialized". The purpose of initialization is to start the system at a known position by pre-setting the correct whole and fractional lane counts for that position. Once initialized, the Raydist system keeps track of the whole and fractional lane counts to a resolution of hundreths of a lane. When something happens that causes the whole lane count to "slip", the system can be "re-initialized" by re-setting the

6.6 MINIRANGER

We had significant experience in operating Miniranger III equipment from other surveys, so we operated it ourselves in the Charleston survey.

Miniranger ranges have a probable error of ± 2 meters as stated in the Miniranger System User's Manual. Discussions with a Motorola representative indicated that their probable error is actually 1.67 sigma. Since we are interested in expressing accuracies in terms of 2 sigma, we multiplied the probable error figure by (2/1.67) (= 1.20) to get a range accuracy of ± 2.4 meters (2 sigma, 95%).

The position accuracy of the Miniranger system depends on the range accuracy and the geometrical configuration of the system. We used two Miniranger ranges for Miniranger position fixes, and restricted the crossing angles from these ranges to between 30 and 150 degrees. Miniranger position accuracy in general is:

$$\text{Position Accuracy} = \frac{Ra}{\text{SIN}(a/2)} \text{ meters}$$

Where: Ra = Range accuracy, in meters
a = crossing angle, in degrees

So with $30° <= a <= 150°$
and $Ra = \pm 2.4$ meters,

Position Accuracy = ± 9.3 meters (2 sigma, 95%)

Rounded up to the nearest whole meter, this is ± 10 meters and is the Miniranger positioning accuracy figure we use later in this report.

Miniranger III is a line-of-sight system. The equipment we used was limited to a maximum range of about 20 miles. Miniranger was used as the reference positioning system for the entire River Route and the Ocean Route to about 20 miles offshore.

6.7 GPS

Personnel from the Office of Research and Development operated the GPS equipment during the survey since they had prior experience with the system.

The GPS network at the time of the survey comprised 5 satellites. One of these had an inaccurate reference clock

The Coast Guard Office of Research and Development has an ongoing project to study the Loran-C signal stability in selected harbors along the CONUS coast. Reference 9 describes this Harbor Monitor program in detail and presents the results of the study for the Northeast and Southeast U.S.

It is beyond the scope of this project to explore the feasibility of Differential Loran-C in general. However, we collected sufficient Harbor Monitor data during the survey to see how Loran-C corrections applied to the survey data would affect the accuracy of HHE Loran-C in Charleston.

a. **Folly Beach Harbor Monitor.** As part of the Harbor Monitor Program, the Coast Guard Research and Development Center, Groton, CT has established a Harbor Monitor at the former Folly Beach, SC Loran-A station. This site was used during this project to monitor and record the Loran-C signals used to correct the surveyed waypoint TDs. A discussion of the data collected at the monitor during the survey is presented later in this report.

b. **Annual Stability and Error prediction.** The Harbor Monitor program has measured an annual stability of ± 18 meters at the Folly Beach Harbor Monitor. This does not take into account receiver dynamics, however. Reference 9 predicts a 99.9% probability cross track error of less than 45 meters for all of the reaches in the River Route. This prediction includes 16 meters of error attributed to vessel dynamics and operator steering ability. These figures were the basis of our 30 to 40 meters (95%) estimate for repeatable accuracy in the Charleston area.

6.5 LORAN-C SIGNAL MONITORING

The Loran-C signals are known to vary from moment to moment due to environmental and other factors. These variations will affect any waypoint survey effort such as in this project. The optimum case would be to measure the Loran-C TDs of all the desired waypoints at exactly the same instant in time. However, this is not feasible since they are located many miles apart. This time referencing can be effected, however, by monitoring the Loran-C signals continuously while collecting waypoint Loran-C TDs. By knowing what the Loran-C TDs should be at the monitor site (from a long term average, for example), one can determine how much the TDs varied from these nominal values for any given moment and correction values can be developed from these variations. These correction values can then be applied to the waypoint Loran-C TDs that were measured at the same moment resulting in waypoint Loran-C TDs that are normalized to the nominal values for that area. This procedure was explored during this project.

The same principle can be used to reduce or eliminate the Loran-C signal variations during real-time navigation. As the Loran-C receiver on board a vessel is receiving Loran-C signals, one could input signal corrections that are based on measurements by a shore-based monitor measured at the same moment. This would have the effect of normalizing the real-time Loran-TDs to nominal values. This process, applying real-time corrections to real-time Loran-C TDs, is know as Differential Loran-C.

There are several factors that must be considered when applying corrections to measured waypoint or real-time Loran-C TDs.

First, do the Loran-C signals vary uniformly over the area of interest? If so, one monitor may suffice for determining the corrections for waypoints in the entire area. If not, several monitors will be needed to cover the area and the corrections would be developed from (presumably) the closest monitor to a given waypoint.

Second, how much do the signals vary from one moment to the next? One may find, for example, that for one area corrections computed once every hour may be satisfactory, whereas another area may require corrections every 5 minutes.

Finally, do the Loran-C signals vary enough to make any practical difference in the accuracy achieved? If there is an insignificant amount of error due to the long term (or short term) Loran-C signal variations, then no corrections are necessary either to the surveyed waypoint TDs or to TDs measured during use of the waypoint TDs in the repeatability mode.

The survey origin is assigned as waypoint #25 in each waypoint data file. The position of the survey origin is:

State Plane	X:	713.813 km
	Y:	94.877 km
WGS-72	Latitude:	32° 41' 02.83" N
	Longitude:	79° 53' 19.28" W
NAD-27	Latitude:	32° 41' 02.27" N
	Longitude:	79° 53' 19.58" W
Loran-C 7980	MY:	45510.51 usec
	MZ:	60557.02 usec

For the record, the position of the Folly Beach Harbor Monitor antenna is:

State Plane	X:	713.813 km
	Y:	94.861 km
WGS-72	Latitude:	32° 41' 02.30" N
	Longitude:	79° 53' 19.27" W
NAD-27	Latitude:	32° 41' 01.74" N
	Longitude:	79° 53' 19.57" W
Loran-C 7980	MY:	45510.47 usec (long term average)
	MZ:	60557.07 usec

6.4 LORAN-C

We used the GRI 7980 Loran-C chain, Yankee (Y) and Zulu (Z) secondaries in the survey. This secondary pair was selected because it offered the best overall Loran-C 2 drms accuracy and signal strengths for the Charleston area. The chain and station parameters are shown below.

GRI: 7980 - Southeast US

Station Name	Emission Delay, in Usec	Location Latitude, N Deg-Min-Sec	Location Longitude, W Deg-Min-Sec
M - Malone, FL		30°43'33.02"	90°49'43.60"
Y - Jupiter, FL	45201.89	27°01'58.39"	80°06'53.43"
Z - Carolina Beach, SC	61542.73	34°03'46.08"	77°54'46.65"

Appendix C lists the waypoint definitions in State Plane, NAD-27, and WGS-72 coordinates. The surveyed Loran-C TDs are also shown. They are the object of the survey and will be discussed later in this report.

6.2 WAYPOINTS - OCEAN ROUTE

The Ocean Route waypoints were provided to us by the Navy. Supplement C1 lists the waypoint definitions in State Plane, NAD-27, and WGS-72 coordinates. The surveyed Loran-C TDs are also shown. They are the object of the survey, and will be discussed later in this report.

6.3 SURVEY ORIGIN

A local coordinate system origin point is needed for flat plane computations during data reduction. The choice of origin point location is somewhat arbitrary, but the location (state plane, latitude/longitude coordinates) and the Loran-C TDs must be known (measured).

The receiving antenna of the Folly Beach Harbor Monitor was initially selected as the survey origin because the Loran-C TDs of this site are "known" (i.e. a long term average has been established) and the state plane (and therefore latitude/longitude) coordinates could be measured based on a nearby HC site. Also, the monitor site is roughly centered in the survey area, including both the River and Ocean Routes.

Compass bearing and tape measurements were made from the Folly Island Loran Tower (an HC site) to the Folly Beach Harbor Monitor antenna: 371.85 feet at 271.15° magnetic. Initially the 5 degree magnetic variation was incorrectly applied (added instead of subtracted), resulting in the incorrect true bearing, and therefore a position that was offset from the monitor antenna by 16 meters at 0° true. Since the error was discovered after data collection and reduction had begun, we decided to keep the survey origin at the offset position. We computed the Loran-C TDs at the survey origin by offsetting the long term average TDs at the monitor antenna by the same 16 meters at 0° true. The TDs of the survey origin were not needed until much later in the survey, and so not having the correct TDs had no impact on any computations made up to the time the error was discovered.

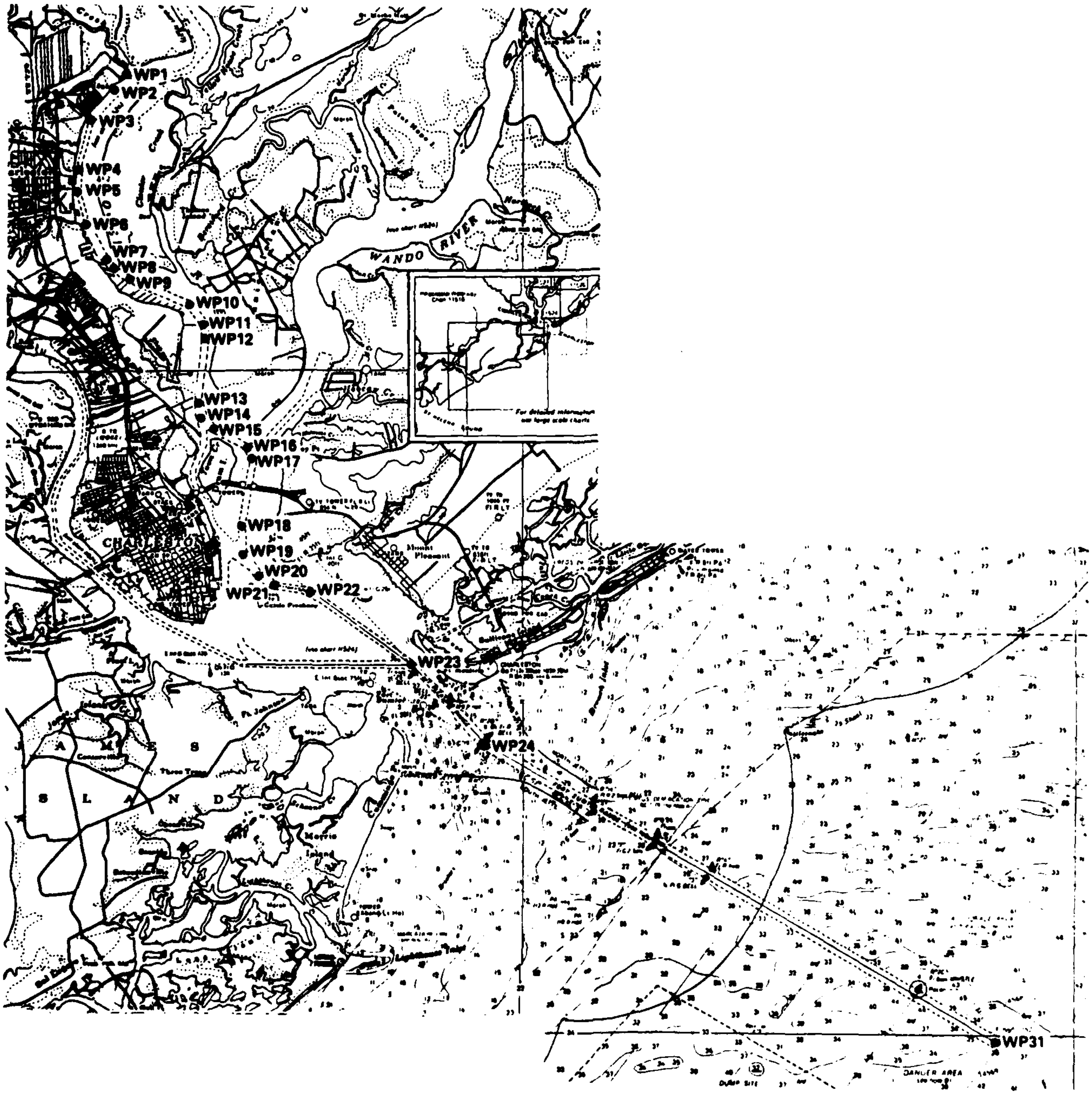


Figure 6-1

River Route Waypoints

6.0 PROJECT PLANNING

Various phases of the project were accomplished prior to doing the field survey work. These included selecting the waypoint positions, understanding the operational aspects of the various navigation systems, selecting the Horizontal Control sites for the reference positioning system, and digitizing chartlets for the routes of interest.

6.1 WAYPOINTS - RIVER ROUTE

The River Route waypoints were selected as the turnpoints on the centerlines of the main channels in the Cooper River. Trackpoints (waypoints that occur along a straight line reach instead of a turn) were added in several long channel reaches, anticipating that they would be needed to achieve the stated accuracy goal. For the remainder of this report trackpoints will be referred to as waypoints because the same procedures are used to survey trackpoints as are used for waypoints.

In other surveys, standard nautical charts were used to identify the waypoints and determine the latitude/longitude for the waypoints. This is inadequate for precision work, because the chart scale and the inherent charting accuracy translates to tens of meters of error in the waypoint positions.

For this project, we used the latest US Army Corps of Engineers Dredging charts for determining the waypoint positions. These charts are scaled at 1" = 200 feet. We determined that we could measure points on the charts to within 1/2 mm which translates to approximately 4 feet. The dredging charts are printed with State Plane coordinates (South Carolina South region) and thus the waypoints are defined in State Plane coordinates.

The waypoint state plane coordinates were converted to latitude/longitude (NAD-27) using the SPGEO program.

The waypoint NAD-27 coordinates were converted to WGS-72 coordinates using the DATUM program.

Figure 6-1 shows the approximate locations of the waypoints on a chart of the Charleston area. The waypoints were arbitrarily numbered 1 to 24, and 31, beginning with the waypoint that is the farthest upriver. The gap in numbering between 24 and 31 is because each waypoint data file can contain only 25 waypoints, and waypoint 25 is reserved for the Local Origin waypoint. Waypoint 31 was contained in a separate waypoint data file (as waypoint 1) but is no different from the other waypoints.

5.Ø SOFTWARE

Various computer programs were used in the execution of this project. The title and a brief description of each program is shown below.

TDSS - Time Difference Survey System (April 1981) for Internav LC4Ø4 Loran-C Receivers. This program is used for collecting Loran-C and Miniranger data. Reference 2 contains a description and program listing of TDSS. Modifications to the TDSS program were necessary for this project to display more information on the computer CRT during data collection and to accomodate several Miniranger hardware configurations.

COMPAR - The program used to analyze and reduce data collected using TDSS. Reference 2 contains a description and program listing of COMPAR. Modifications to the COMPAR program were necessary for this project to read in different data formats (GPS and Raydist) and to present analyzed data in a scatter plot.

GPSDAT - Data translator program for converting GPS positions (latitude/longitude, WGS-72) to State Plane positions. This program is a combination of the DATUM and GEOSP programs plus a data format conversion from one hardware system to another. Refer to the DATUM and GEOSP program descriptions below.

EEE1ØA - A program that computes the Loran-C TDs, baseline lengths, crossing angles, gradients and other Loran-C related parameters, given a geodetic position. EEE1ØA computations are done using a saltwater model of the earth, in WGS-72.

SPGEO - State Plane to Geodetic (NAD-27) coordinate conversion. Reference 6 contains the mathematical equations upon which this program is based.

GEOSP - Geodetic (NAD-27) to State Plane coordinate conversion. Reference 6 contains the mathematical equations upon which this program is based.

DATUM - Geodetic Datum conversion program (e.g. NAD-27 to WGS-72). Reference 7 contains the abridged Molodensky formulas upon which this program is based.

DIGTES - Chartlet digitizing program. Reference 8 contains a description and program listing.

TRANSF - Transfer program to combine the digitized chartlet data and the waypoint data, and transfer to PILOT tape. Reference 8 contains a description and program listing.

performance of today's receivers beyond what was available when PILOT was developed.

4.0 EQUIPMENT

Various equipment suites were used for each phase of the project. System interconnect diagrams are shown in appendix B. The major components of each suite are shown below.

4.1 DATA COLLECTION

Hewlett Packard HPHP9845B Desktop Computer
Internav LC404 Loran-C Receiver
Motorola Miniranger III Ranging System
Magnavox Zset GPS receiver/data collection system
Teledyne/Hastings/Raydist Raydist-T receiver/data collection system

4.2 DATA REDUCTION

HPHP9845B Desktop Computer
HP9895A 8" Dual Floppy Disk Drive
HP2648 Data Terminal
HP9871 Digitizer

4.3 VERIFICATION

Same as data collection equipment, plus:

USCG PILOT Terminal
LC404 Loran-C Receiver

4.4 DEMONSTRATION

USCG PILOT Terminal
LC404 Loran-C Receiver

A special mention of the PILOT system is in order. PILOT uses Loran-C TDs from a receiver as a real-time input and displays vessel position with respect to predetermined tracklines and waypoints. The presentation is both alphanumeric (numbers quantifying distance to go to a destination, cross track error, etc.) and graphic (vessel position shown on a chart-like background). Magnetic tapes store the previously surveyed waypoint TDs and digitized chart data. Reference 3 describes the PILOT system in detail.

PILOT was developed as a prototype system to demonstrate the feasibility of using Loran-C for HHE applications. We used PILOT in this survey to validate the survey data and to demonstrate the use of Loran-C in the repeatable mode in Charleston.

Many commercial Loran-C receivers have the same or similar alphanumeric display features as PILOT. The choice of an operational system for Loran-C applications should be based on the features in commercially available receivers and not on those of PILOT. Advances in the technology have improved the time using Loran-C (repeatability), but one would never know the true geodetic coordinates of the site. The electronic reference system, on the other hand, is specifically designed to measure geodetic positions, usually i. a flat plane coordinate system such as a State Plane coordinate system.

b. The repeatable accuracy achieved when using the visual reference system is not quantified. One can, for example, collect data while visually perceiving that the data collection vessel is lined up on a range marker and halt data collection when perceiving that the vessel is not lined up exactly on the range marker. The fundamental assumption made is that if the vessel is perceived to be exactly on the range marker then the cross track error due to the visual reference system is very small or zero. This assumption is carried through all of the subsequent data reductions. In fact, the cross track error is substantial. For example, with range markers separated by one mile and a vessel stationed four miles from the forward range marker, one can have as much as ± 40 meters cross track error even though it appears that the vessel is "on the range". Also, there is no reliable way to determine along track distance except with buoys and fixed aids. The electronic reference system, on the other hand, yields reference position data with which one can compute cross and along track errors and repeatable accuracies. Further, since the systematic error of the electronic reference system is quantifiable (by calibration), one can determine the true geodetic accuracy.

The electronic survey method was selected for this project because of the need for a geodetic reference and the need for quantifying the accuracies achieved.

Departures and improvements to the electronic survey method presented in reference 2 are documented in this report and will be discussed as they arise.

One US Survey Foot = 1200/3937 meters exactly

Miles - Always means Nautical Miles.

3.3 SURVEY METHODS

Two primary survey methods have been developed by the Coast Guard for conducting HHE Loran-C surveys: the visual survey method, and the electronic survey method. Reference 2 presents the technical details of the two methods.

The difference in the two methods lies in the type of reference positioning system used to determine the waypoint positions being surveyed.

a. The visual survey method uses visual aids to navigation, such as range markers, buoys, and fixed aids as reference points. Loran-C data is collected while the vessel is tied up at the fixed or floating aids and while underway and lined up on range markers. The Loran-C data is analyzed using regression techniques to determine the Loran-C TDs at the desired waypoints, usually at the crossings of two sets of visual range markers.

b. The electronic survey method uses an electronic positioning system such as Miniranger III to determine the vessel's geodetic position while Loran-C data is collected. Transponders are erected on geodetic reference points, such as Horizontal Control Stations established by the US Army Corps of Engineers, the National Oceanic and Atmospheric Administration, and the Coast and Geodetic Survey. The ranges from two or more transponders are measured at the point of interest, and then the geodetic position of that point can be mathematically determined knowing the ranges and the geodetic coordinates of the reference points. The Loran-C and reference position data is analyzed using regression techniques to determine the Loran-C TDs at the desired waypoints, usually the turnpoints of the channel centerlines as defined on US Army Corps of Engineer dredging charts.

Both survey methods result in Loran-C TDs that can be used for repeatable navigation from one waypoint to another. There are, however, two fundamental differences between the two methods.

a. Using the visual reference systems, the true geodetic positions of the waypoints are not determined. For example, one could visit the site where two sets of range markers cross, measure the Loran-C TDs at the crossing, and then return to the same site time after

- Confidence in HC site position as stated on the description sheet.

Each candidate HC site was visited during a pre-survey site selection trip. The list of sites was revised based on this trip. Additional sites were identified and used during the survey. Appendix D lists the HC sites that were used in this project.

Figure 6-2 shows the approximate locations of the HC sites on a chart of the Charleston area.

6.10 DIGITIZED CHARTLETS

The PILOT System displays on its screen a digital chartlet of the harbor area where the vessel is presently located. The data comprising the chartlet is contained on a magnetic tape cartridge that is plugged into the PILOT terminal. The process by which the data is encoded and stored onto the tape is called <u>digitizing</u>. A device called a Digitizer is used to convert discrete points to digital values. Features on a nautical chart, such as channel boundaries, coastlines, centerlines, etc. are digitized by selecting points along those features that, when connected with straight lines on the PILOT terminal display, would fairly represent the original features.

Each section of a channel is digitized into separate chartlets in two different scales. One chartlet, called a **Master**, shows an overall view (small scale) of the waterways, landmasses, and other features surrounding the channel. A series of chartlets, called **Details**, show a detailed view (large scale) of the particular channel. A given channel is divided into several Details depending on the length of the channel and the chart scale.

Each direction of the desired route had to be digitized separately because of the way the chartlet data is structured. This effectively meant digitizing all channels twice.

All of the chartlets for Charleston were digitized prior to the field survey. However, many were re-digitized on scene due to changes made during surveying.

Reference 8 describes the procedures used to digitize chartlets.

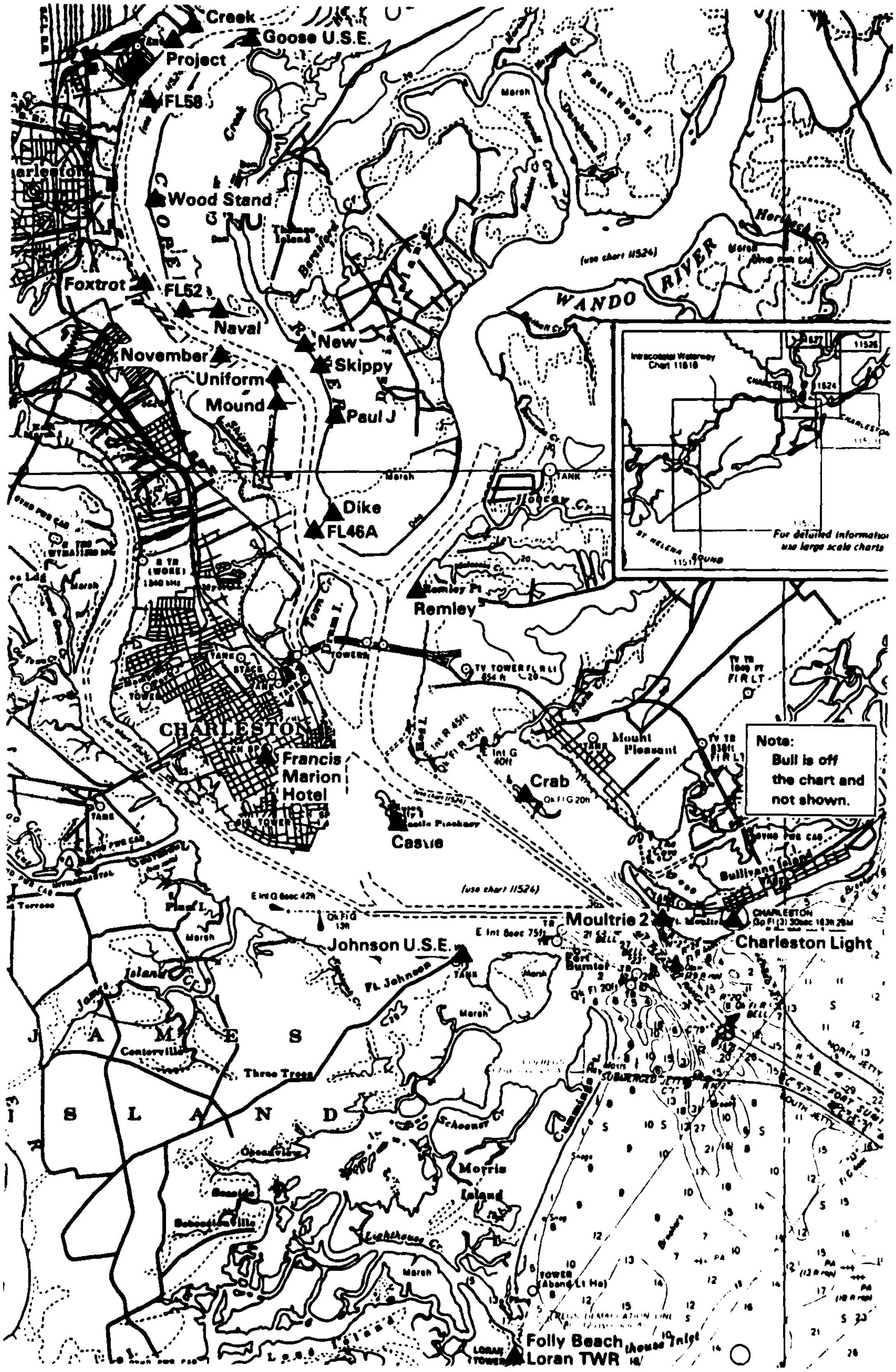


Figure 6-2

Horizontal Control Sites

7.0 PROJECT EXECUTION

Prior to collecting data, each system was calibrated to the extent possible, and daily checks were done on each system to ensure correct operation.

The data collection and analysis was in two phases for each of the routes: the Survey phase and the Verification phase. The main purpose of the survey data collection and analysis was to determine the Loran-C waypoint TDs, while the purpose of the verification was to confirm the validity of the surveyed waypoints. Data was collected for the GPS and Raydist systems during River Route verification to determine the feasibility of using these systems as reference positioning systems in the Ocean Route beyond Miniranger range (i.e. beyond 20 miles from shore).

7.1 MINIRANGER CALIBRATION

Even though the Miniranger range accuracy is ± 2 meters probable error, we used ± 2 meters as our accuracy requirement for calibration as though it was a 2 sigma, 95% error figure (the actual 95% figure is 2.4 meters as discussed above). The complete calibration procedure is contained in the User's Manual. The procedure involves setting up the Miniranger Receiver/Transmitter (R/T) units at one end of a measured calibration range with each of the Universal Reference Stations at the other end and then adjusting the measured range of each reference station so that it agrees with the known distance within ± 2 meters. We measured a distance of 432 meters along the rails of a railroad track on a flat concrete dock for our calibration range. Although we did not quantify the amount of error in this range, we believe it is much less than ± 2 meters.

We calibrated the Miniranger system on this calibration range many times during the survey whenever any repairs or adjustments were made to the Miniranger equipment or whenever our daily system checks indicated that the Miniranger system was out of calibration.

7.2 HORIZONTAL CONTROL SITE POSITION VERIFICATION

Since we were using second and third order HC stations, we felt it was necessary to confirm by measurement the accuracy of the published positions for each of the HC stations we intended to use in the survey. The decision was a wise one as we found several stations that were not in the positions shown on the HC description sheets. In fairness, we should say that the stations with questionable positions were ones that were mostly submerged and therefore not positively identified (e.g. we found a concrete post in the location indicated in the verbal description but could not read the brass marker).

To verify the positions of each of the HC stations, we measured the distance from a given station to two other stations using the Miniranger system. We compared the measured distances to the distances computed based on the published positions for the stations. If the distances agreed within $\pm$ 2 meters (the range accuracy of the Miniranger), we considered the position of the common station verified. All HC stations we used in the survey were verified using this procedure.

Note that this procedure checks all of the HC stations relative to each other, but not to an independently known position. We used second and third order sites but from past experience we knew that the stated positions of such sites can sometimes be in error. Our confidence in the true positions of the HC stations is based on the fact that they checked so well relative to each other. Said another way, if one's wrong, they're all wrong.

Despite our best efforts during the pre-survey site selection trip, we spent a significant portion of the survey identifying and recovering more HC sites because of the position problems mention above, and because we overestimated the coverage area of some of the previously selected sites. In some cases, we found established markers in suitable locations to meet our needs. There were times, however, when markers did not exist in places where we needed them to get the coverage we required. In these cases, we were forced to "survey in" our own markers.

The procedure to do this was similar to the one we used for checking the positions of established markers. We started with two established HC stations in which we were confident of the positions. We measured the distances from these known stations to a third HC station whose position is unknown. We then computed the position of the unknown station given two known positions and two known ranges. Standard trilateration equations were used for this calculation. The positions of the "surveyed in" stations were verified using the same procedure as other stations using different stations than the ones used to define the new stations whenever possible.

7.3 GPS SYSTEM INITIAL VERIFICATION

At the beginning of the survey we collected GPS data for a 4 hour period at a fixed point whose state plane (and therefore latitude/longitude) coordinates were known. The results showed that GPS could measure the position of this site with a geodetic accuracy of $\pm$ 20 meters. This supported our estimate of GPS available accuracy predicted earlier.

The validity of using GPS as a reference positioning system would not be based solely on this test, but would be based on the results of the daily data collections. This will be discussed later in this report.

7.4 RAYDIST SYSTEM INITIAL VERIFICATION

At the beginning of the survey we attempted to collect Raydist data in the area where the vessel docked. Due to the propagation nature of the frequencies that Raydist uses, the signals are severely delayed and attenuated over land. Also, the Charleston Raydist network is set up for optimum coverage off shore, not in the river. We found these conditions to be true in that we could not receive useable Raydist signals anywhere upstream of approximately waypoint 24. This behavior was confirmed by both the Navy's Raydist system operator and by Raydist company representatives. Therefore we only collected Raydist data on the Ocean Route.

7.5 SURVEY DATA COLLECTION PROCEDURE

Several teams were established for the data collection effort, communicating by two-way radio to coordinate their movements. The Base team, comprising usually two people on board the data collection vessel, was responsible for running the data collection computer system and directing the movements of the other teams. One or more Miniranger teams, comprising two people per team, were deployed to set up miniranger reference stations at the HC sites previously identified.

The data collection procedure was as follows.

a. Miniranger System Verification. Each morning before beginning the data collection, we set up each of the reference stations on a nearby HC station and measured the distance to this station from the vessel while moored at a reference dockside position. (We determined the reference distance to this mark by measuring with the Miniranger system immediately after it was calibrated.) If the morning measurement agreed with the reference measurement within ± 2 meters, we considered the system calibrated. If the measurement was not within ± 2 meters, we completely recalibrated the system on the calibration range before proceding.

b. Loran-C System Verification. Each morning before beginning the data collection, and again each evening after ending the data collection, we measured the Loran-C TDs at the reference dockside position. This check was intended as a check on the equipment operation (proper receiver lock-on, proper data communication between the receiver and the computer, etc.), and not as a calibration of the Loran-C TDs at that position. A minimum of thirty samples were collected during the dockside sampling, and a printout of the results (mean, standard deviations) indicated that the system was or was not operating correctly.

c. Miniranger Remote Site Setup. We deployed the Miniranger teams to the HC station sites needed for the start of the day's data collection as soon as the systems were checked out. Depending on the location of the HC stations, the teams traveled either by vehicle, foot, or rubber boat carrying the Miniranger Reference Stations, batteries, tool kits, HC station description sheets (first visit only), ladders, tie-down gear, hand-held radios, and other miscellaneous equipment. Once the reference stations were erected, the team verified correct equipment operation while communicating with the base team. The Miniranger team remained at the HC station when it was located in a public place (for security reasons) or when the equipment was needed for a subsequent location. Many times, however, the reference station equipment was left unattended while the team set up other stations. This allowed maximum use of available time for data collection, since a significant amount of time was spent waiting for the Miniranger teams to transit to the locations and set up the equipment.

d. Time Synchronization. There was no easy way to automatically synchronize the sampling intervals of the three systems because of system hardware incompatability. We decided to use the HP9845 Real Time Clock as the reference and manually synchronize the internal clocks of the other two systems to it. This was done with a vocal "mark" at a known time. We found we could synchronize the clocks to within one half second of each other repeatably.

The sampling interval of the GPS system was not necessarily fixed. It depended on what the GPS satellites were doing when a sample was requested; the interval varied from 8 to 14 seconds for a desired 12 second sampling interval. Since it was vital to have time syncronization to within one second, we sampled the GPS system at twice the sampling rate of the HP9845 system (6 second intervals), and then interpolated between data samples to get the position data for the correct time periods. The interpolation process was done post-data collection and was actually part of the computer program that downloaded the GPS data to the HP9845 (more on this in the section on data reduction).

e. Data Collection Runs. A data collection run consisted of taking data either in the vicinity of a waypoint (called a "hover") or along the centerline (and centerline extension) of a channel starting about 1 kilometer before one waypoint and ending about 1 kilometer beyond the next waypoint. Each trackline was surveyed in both directions in separate runs.

There were several tracklines where data could not be collected 1 kilometer away from a waypoint on the centerline extension because of shallow water and other hazards. The 1 kilometer rule-of-thumb was so that the vessel's course and speed would be stable by the time the vessel passed through the waypoint.

There were places where waypoints or tracklines were located in overlapping areas of two pairs of Miniranger stations. Usually this occured at the edges of the coverage areas of both Miniranger pairs, i.e. where the crossing angles of each pair approached 30 degrees. In these cases, data was collected in separate runs for each of the Miniranger station pairs, to minimize the chance of errors in one pair dominating the results.

Some tracklines could not be covered by a single Miniranger station pair. In these cases, data was collected using one station pair for half of the trackline and another station pair for the other half. This made data reduction slightly more complex but not unmanageable.

f. Loran-C and Miniranger Data. The Loran-C and Miniranger data was collected using a Hewlett Packard HP9845B Desktop Computer. The HP9845 sampled the two Miniranger ranges and the Loran-C TDs at a specified sampling time interval (usually every 12 seconds) and plotted the present position relative to the intended trackline on the CRT. The sample times, ranges, and TDs were printed on the HP9845's internal printer along with status and error codes when abnormal conditions were detected. The interval timing was done by a peripheral Real Time Clock. At the end of each data collection run the data was stored on magnetic tape for data reduction on shore. Appendix E shows a sample of the raw Loran-C and Miniranger data.

g. Raydist Data. The Raydist data was collected using the Raydist Director and data collection system. The Raydist system measured the red and green lane counts and converted them to latitude/longitude (WGS-72) positions. The data was stored on magnetic floppy disk at the end of each data collection run.

h. <u>GPS Data</u>. The GPS data was collected using the Z-Set GPS receiver and data collection system. The Z-set uses all available GPS satellites (usually 4 during our survey) to determine present position (latitude/longitude, WGS-72). The GPS data was stored on magnetic tape at the end of each data collection run.

i. <u>Loran-C Monitor Data</u>. As discussed earlier, the Harbor Monitor at Folly Beach was used as a monitor reference for the Loran-C TDs. High density data was automatically collected by the Harbor Monitor Data Collection Set in its normal mode. High density data collection consisted of sampling the Loran-C TDs every 30 seconds round the clock, and computing and storing 15 minute averages, statistics, SNRs, and error flags. The raw samples taken every 30 seconds are not saved by the monitor data collection set. For our survey, we simply downloaded the monitor data approximately every day for our use without disturbing the monitor's normal functions. The Harbor Monitor data collection set saves the most recent 2 to 3 days worth of averages, and so downloading every day resulted in overlapping datasets, a welcome redundancy. The downloaded data was stored on magnetic tape for use during data reduction.

Correction values for each 15 minute time period were computed from the raw data by subtracting the 15 minute average TDs from the long term average TDs. This gave a set of correction values for each 15 minute period.

7.6 SURVEY DATA COLLECTION COMMENTS

We collected River Route Loran-C and Miniranger data as planned. Each trackline between waypoints was surveyed at least twice (once in each direction), and in some cases more, depending on the confidence we had in a given data run. There were times when a given data run was suspect, usually because of erratic Miniranger behavior. We identified most Miniranger problems to be related to local interferences and signal reflections, especially in the vicinity of large Navy vessels along the dock area. Sufficient good data was collected to properly determine the Loran-C TDs at all waypoints and along all tracklines.

We collected Loran-C data in the entire Ocean Route, but we collected Miniranger data only to 20 miles offshore.

GPS data was not collected during River Route survey (it was collected for all other phases.) The GPS satellites were only available from approximately 2300 to 0300 each day. Our River Route data collection efforts were during daylight hours to facilitate setting up the remote Miniranger sites and operating in an unfamiliar river. We did not have the staff necessary to collect data for more than about 12 hours per day.

We collected Raydist data only on the Ocean Route because we could not reliably track the Raydist signals in the River Route except between River Route waypoints 24 and 31. We estabilshed an initialization point between these two waypoints because it was in Raydist's optimum coverage area.

We found that we could usually initialize Raydist using Miniranger positions near Fort Sumter. When the Raydist accuracy was re-checked against Miniranger, they often compared within 9 to 16 meters in the same area. However, frequent whole and fractional lane slips occured during surveying (and verification) in the Ocean Route.

7.7 SURVEY DATA REDUCTION PROCEDURE

Data reduction in general involves comparing the data of one navigation system against the data of another system, statistically determining the waypoint positions in terms of the units of measure of each data system, and comparing the difference between the two systems along the tracklines.

One of the two systems being compared is called the reference system, and the other system is called the compared system. As comparison implies, it is the difference between the positions of the two systems that is computed. The reference system becomes the axis (or in some cases the origin) of the comparison plots, and the data plotted, therefore, represents the amount of error of the compared system with respect to the reference system.

First, the data from each of the two systems is read into the data reduction computer from tape. Next, the data sets are purged of known, bad data samples noted during data collection. A bad data sample might occur when the vessel was making sharp turns or drastic speed changes, when an error condition was indicated on one of the receivers or when the data transfer corrupted a data sample. Notes were made on the raw data printouts indicating which data samples were edited out during the data reduction. In cases where many samples were edited from a given data set the edited version was stored on tape in a separate file. The original raw data sets remained unchanged on tape.

Next, both systems are converted from their normal units (Loran-C TDs, Miniranger ranges, latitude/longitude, etc.) into State Plane (X/Y) coordinates. The corrections based on the Loran-C Monitor data, if applied, are applied to the surveyed Loran-C data in this step.

Then, the along track and cross track (At/Ct) positions of each data sample are computed with respect to the trackline along which data samples were taken. For this comparison, the trackline is defined by the line connecting the latest waypoint coordinates of the compared system. When the first comparison is done for a given trackline, the waypoints may be predicted values. As better values are determined during the data reduction process, they are entered into the waypoint data file and used in subsequent computations.

Next, one of several analyses and plots are done on the data. The results of a given analysis may indicate that the waypoint coordinates of the compared system need to be adjusted to reduce the overall error. After the adjustment is done, the X/Y and At/Ct computations, analyses and plots are repeated. The entire process is repeated until the errors from all of the data sets for a given waypoint are minimized. The analysis on the final waypoint values is a measure of the error for that waypoint. Data reduction is an iterative, time consuming process.

A fundamental assumption in the data reduction program is that a flat plane is a reasonable approximation of the earth for the two systems being compared. This has been found to be a good assumption for distances encountered during HHE surveys.

A general description of the data analysis and plot functions follows.

a. Reflect. Reflect at a waypoint applies only to the case of Loran-C as the compared system. Knowing the X/Y coordinates of the waypoint (selected during survey planning), the X/Y coordinates of each sample in the reference system are moved by a delta X and delta Y amount to the waypoint position. The X/Y coordinates of the corresponding data sample in the compared system are then moved (reflected) by the same amount of delta X and delta Y. The delta values are also converted into delta TDs and applied to the Loran-C TD data samples directly. This automated process is repeated for each of the samples in a data set collected at a waypoint. The result is a set of X/Y coordinates and Loran-C TDs at the waypoint position. Of course, the data samples will not converge exactly on the waypoint because of variations in the signals, noise, movement of the vessel, etc. Therefore, standard statistical calculations are done on the coordinates of the compared system resulting in mean waypoint coordinates and the standard deviations about the mean. This information gives a measure of quality to the data set, a low standard deviation indicating a good data set. The mean TD values are the "surveyed" values for the waypoint and are used to update the waypoint data file. Figure 7-1 shows a sample Reflect printout.

b. Compare. Compare is a comparison of the compared system data to the reference system data along a trackline or at a waypoint. Compare computes the difference between the X/Y coordinates of the two systems and also the difference between the along/cross track positions of the two systems at each data point. These difference values are the errors of the compared system data compared to the reference system data. Standard statistical calculations are done on the two sets of errors (X/Y and At/Ct), and the mean plus two sigma (called the "95% value") of the errors is computed.

Following the calculations, the At/Ct differences are plotted on a "scatter plot" with At on one axis and Ct on the other axis. The 95% values radius of the At/Ct errors is also drawn on the plot to show the distribution of the errors with respect to the 95% value. Figure 7-2 shows a sample printout of the Compare calculations and scatter plot.

The At/Ct 95% value error figure on the scatter plot is the figure we used for a "bottom line" measure of accuracy for the systems being compared. This is discussed more fully in section 8.

Another plot, shown in figure 7-3, shows the separate At and Ct error values on one axis with along track distance on the other axis. This "At/Ct" plot makes it easy to see the contribution of each error component separately along the trackline. Specifically, it shows at each end of the trackline how much the waypoint needs to be moved in order to reduce the overall error. Generally this is a "fine tuning" of the waypoint values determined with the Reflect.

The amount of waypoint move indicated by the the At/Ct Plot is determined for all data sets for a given waypoint before any move is actually made. The amount of move actually made is determined by observing the quality of each data set indicated in the printed results and then using a weighted average of the individual move amounts. This weighting is subjective and is developed through the experience of many data reductions.

The At/Ct plot also shows if the error increases significantly in the middle of the trackline. If it

```
FILE=WP07B                        SAMPLES= 75.00
START TIME=05:21:17:16:03    STOP TIME=05:21:17:23:27
TD CORRECTIONS:     Wcor= 0.00      Xcor= 0.00      Ycor= .01       Zcor= 0.00
POSITION REFERENCE FILE NAME=BLUE
```

	R1	R2	X	Y
CUMULATIVE AVERAGE	1916.124	345.751	-6.720	19.624
STANDARD DEVIATION	28.063	25.743	.023	.027

```
RESULTS OF REFLECTING FILE WP07BtTDs TO WAYPOINT 7.0000
TRACKLINE=WP07Bt>   START TIME=05:21:17:16:03     STOP TIME=05:21:17:23:27
```

	TDW	TDX	TDY	TDZ
CUMULATIVE AVERAGE	-.008	0.000	45573.082	60531.921
STANDARD DEVIATION	.019	0.000	.017	.015

TD PAIR	WX	WY	WZ	XY	XZ	YZ
CORR COEF	0.000	.302	-.488	0.000	0.000	-.057
SLOPE	0.000	.261	-.372	0.000	0.000	-.050
RESIDUAL	19.237	.016	.013	.004	.022	.015
IND VAR	1	1	1	2	2	1

SAMPLES= 75

Figure 7-1 Reflect Printout

```
MINIRANGER/LORAN-C DATA      FILE * C1011B       SAMPLES = 18
SAMPLES 1 THRU 5 DELETED FROM BOTH, 13 SAMPLES REMAIN
POSITION REFERENCE FILE NAME=AQUA
--------------------------------------------------------------------------------
                            R1, METERS    R2, METERS       X, KM      Y, KM
CUMULATIVE AVERAGE:          751.385       760.500        -4.117     18.050
STANDARD DEVIATION:          148.974       244.759          .156       .200
--------------------------------------------------------------------------------
TWO TD SOLUTION, CHAIN=SEUS   LOPs=YZ
LORAN-C (COMPARED)       POSITION ANALYSIS: C1011Be    REFERENCE WAYPOINT =  11
    FROM WP 10 TO WP 11, ACTUAL TRACK = 143.37°    RMS TRACK = 144.22°
    CROSS TRACK:  AVG DISTANCE =    9.17 METERS   STD DEV =    9.44 METERS
    XY POSITIONS: AVG X =   -4.112 KM      AVG Y =   18.040 KM
       STD DEVS:      X =     .157 KM          Y =     .200 KM
--------------------------------------------------------------------------------
ANALYSIS OF LORAN-C (COMPARED) VS MINIRANGER (REFERENCE) DATA: FILE=C1011Be
    X-DIRECTION:      AVG ERROR =   4.79 METERS     RMS ERROR =   5.46 METERS
    Y-DIRECTION:      AVG ERROR = -10.31 METERS     RMS ERROR =  12.76 METERS
    CROSSTRACK:       AVG ERROR =   1.84 METERS     RMS ERROR =   2.19 METERS
    ALONGTRACK:       AVG ERROR =  -9.05 METERS     RMS ERROR =   9.42 METERS

    RMS RADIAL ERROR (FROM THE ORIGIN):  XY:  13.88 METERS  CT/AT:   9.67 METERS
      95% CONFIDENCE (FROM THE ORIGIN):  XY:  27.11 METERS  CT/AT:  14.90 METERS
--------------------------------------------------------------------------------
```

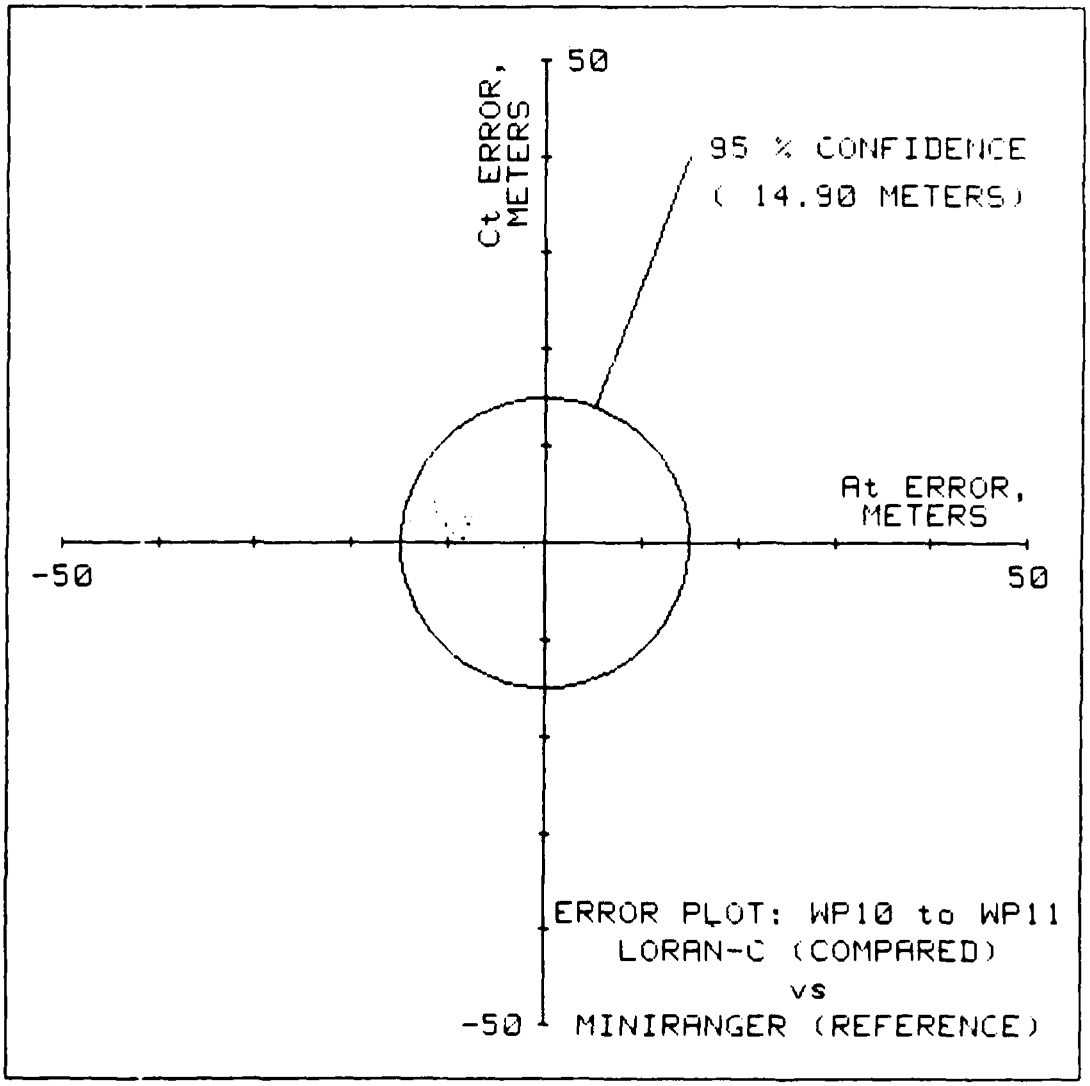
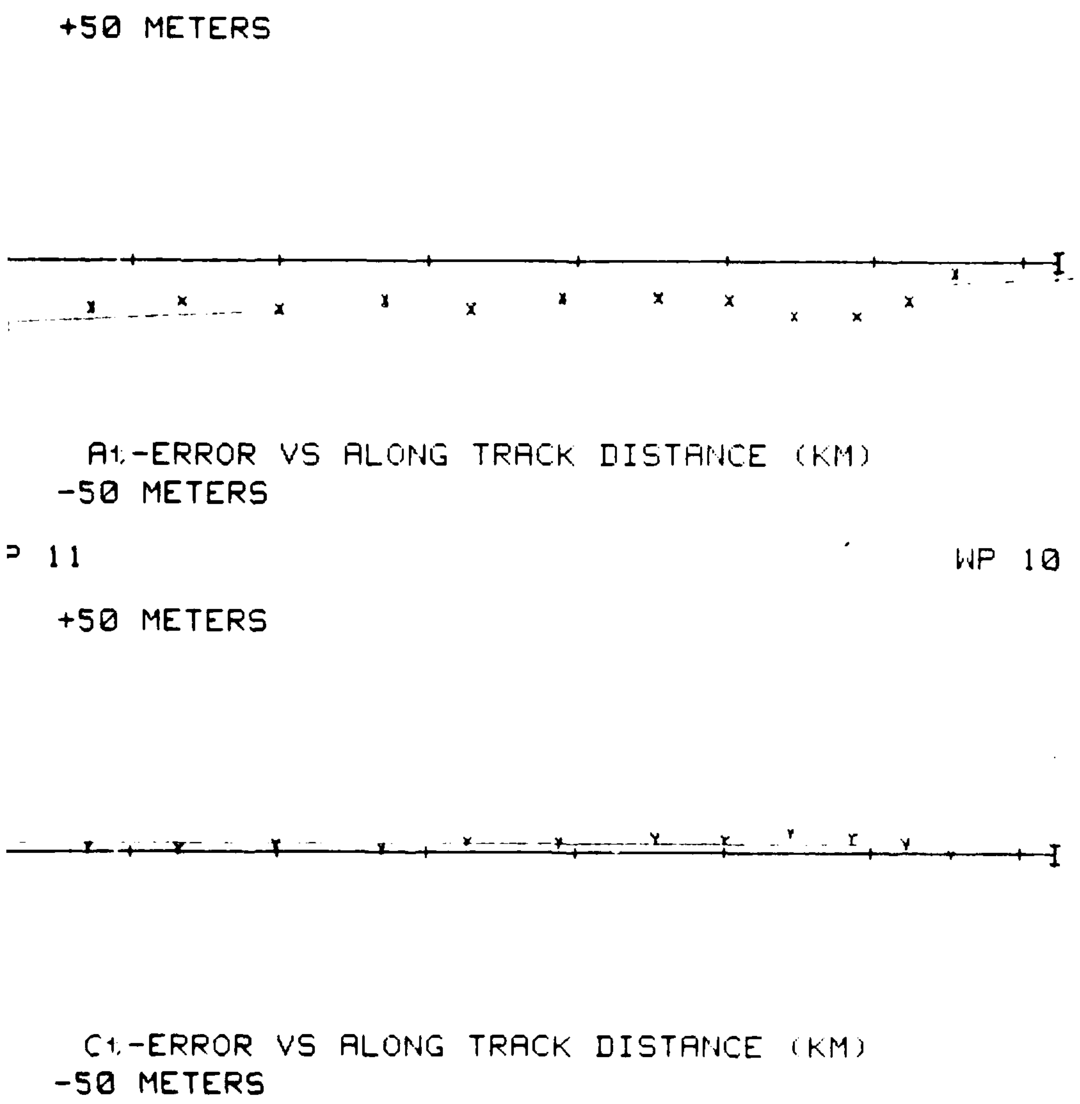
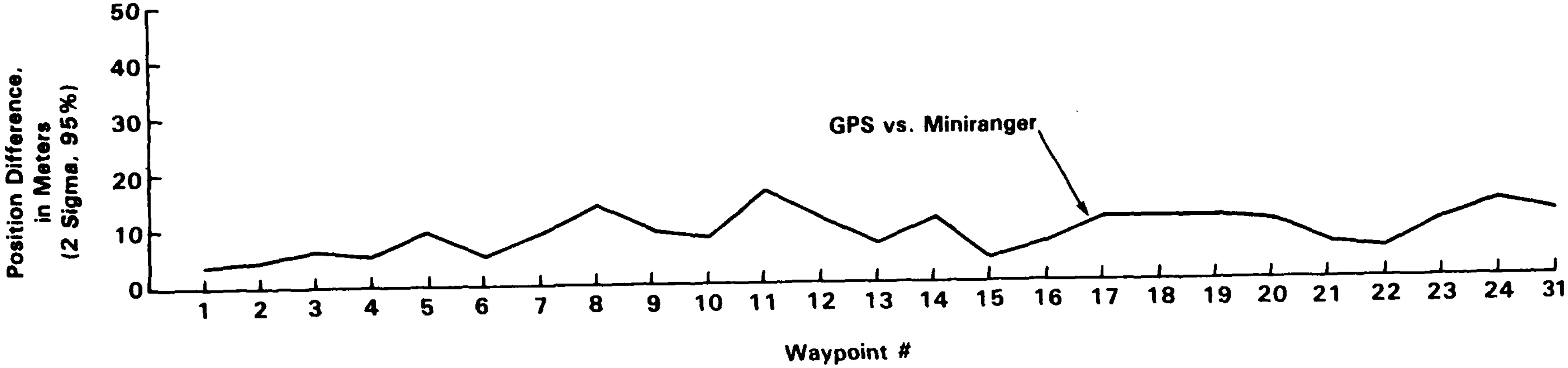


Figure 7-2 Compare Printout and Scatter Plot



gure 7-3 Along/Cross Track Plot

Waypoint Position Comparisons:
Cooper River Route



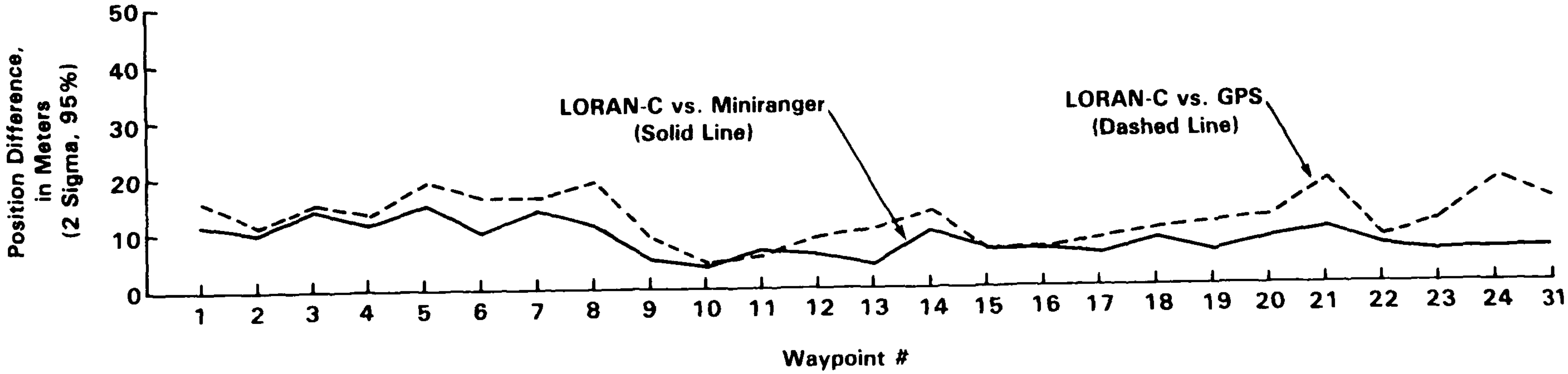


Table 8-2 River Verification Data Summary - At Waypoints (Continued)

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

WP	Data File	Loran-C vs Miniranger At/Ct	D	Mean	GPS vs Miniranger At/Ct	D	Mean	Loran-C vs GPS At/Ct	D	Mean
23	C2223A	5/3	6	6	6/4	7	10	0/1	1	12
	C2322A	3/3	4		0/4	4		5/1	5	
	C2324A	3/0	3		6/9	11		2/12	12	
	C2423A	8/2	8		10/5	11		18/8	20	
	C2423B	7/4	8		15/0	15		21/9	23	
24	C2324A	6/5	8	6	11/9	14	13	20/15	25	18
	C2423A	3/5	6		10/5	11		11/14	18	
	C2423B	1/2	2		10/8	13		8/12	14	
	C2401A	0/6	6		10/1	10		10/3	10	
	C0124A	0/10	10		17/5	18		21/11	24	
31	C2401A	0/2	2	6	2/9	9	11	7/16	17	14
	C0124A	6/7	9		12/2	12		8/8	11	
Mean				8.3			8.6			12.0
Sigma				3.3			3.4			4.3
Mean + 2 Sigma				15.0 meters			15.4 meters			20.7 meters

Table 8-2 (Continued) River Verification Data Summary - At Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

		Loran-C vs Miniranger			GPS vs Miniranger			Loran-C vs GPS		
WP	Data File	At/Ct	D	Mean	At/Ct	D	Mean	At/Ct	D	Mean
17	C1617A	5/0	5	6	5/3	6	11	0/4	4	8
	C1617B	0/0	0		2/5	5		0/6	6	
	C1716A	5/0	5		3/10	10		2/9	9	
	C1718A	2/2	3		8/9	12		3/3	4	
	C1718C	8/0	8		14/0	14		7/3	8	
	WP17A	9/1	9		14/8	16		5/9	10	
	C1817A	4/3	5		3/7	8		9/3	9	
	C1817C	7/5	9		15/4	16		8/9	12	
18	C1718A	1/1	1	8	2/3	4	11	2/3	4	10
	C1718C	8/18	20		7/10	12		2/8	8	
	C1817A	2/7	7		3/13	13		3/8	9	
	C1817C	7/13	15		15/8	17		7/8	11	
	C1819A	7/5	9		5/8	9		12/6	13	
	C1819C	6/2	6		6/9	11		11/11	16	
	WP18A1	0/0	0		1/14	14		1/13	13	
	WP18A2	7/2	7		7/5	9		0/3	3	
19	C1819A	3/1	3	6	3/12	12	11	0/12	12	11
	C1819C	7/1	7		5/8	9		9/8	12	
	WP19A	5/2	5		3/13	13		7/11	13	
	C1920	7/0	7		8/11	14		3/10	10	
	C1920A	6/3	7		-			-		
	C1920C	7/1	7		3/6	7		8/0	8	
20	C1920	9/5	10	7	7/10	10	10	3/7	8	12
	C1920A	3/0	3		-			-		
	C1920C	3/3	4		3/6	8		11/0	11	
	C2021C	92	9		7/7	10		15/4	16	
21	C2021C	5/9	10	10	1/3	3	6	6/12	13	18
	C2122C	10/2	10		7/3	8		21/5	22	
22	C2122C	1/8	8	7	2/3	4	5	2/11	11	8
	C2223A	8/0	8		0/2	2		0/8	8	
	C2322A	3/5	6		7/3	8		2/3	4	

Table 8-2 (Continued) River Verification Data Summary - At Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

		Loran-C vs Miniranger			GPS vs Miniranger			Loran-C vs GPS		
WP	Data File	At/Ct	D	Mean	At/Ct	D	Mean	At/Ct	D	Mean
10	C0910B	5/3	6	2	3/1	3	8	2/1	2	4
	C1009A	2/0	2		5/4	6		5/1	5	
	C1011A	0/0	0		4/2	4		3/2	4	
	C1110A	0/0	0		-			-		
	C1011B	4/2	4		18/2	18		3/2	4	
11	C1011A	7/0	7	7	14/0	14	16	7/0	7	6
	C1011B	13/2	13		10/3	10		3/0	3	
	C1110A	0/0	0		-			-	-	
	C1112A	1/3	3		22/5	23		4/6	7	
	C1112B	6/0	6		15/4	16		6/2	6	
12	C1112A	11/7	13	6	16/5	17	11	17/1	17	9
	C1112B	4/0	4		15/3	15		10/2	10	
	C1213B	3/9	9		5/1	5		1/3	3	
	C1312A	2/4	4		6/0	6		3/3	4	
13	C1213B	1/3	3	4	1/3	3	7	3/8	9	10
	C1312A	2/4	4		9/0	9		7/4	8	
	C1314A	3/2	4		7/6	9		12/5	13	
	C1314B	3/3	4		6/6	8		3/5	6	
	C1413A	7/2	7		3/3	4		10/3	10	
	C1413B	4/1	4		7/5	9		11/8	14	
14	C1314A	10/9	13	10	3/11	11	11	18/2	18	13
	C1314B	2/4	4		2/11	11		4/6	7	
	C1413A	5/7	9		2/10	10		13/3	13	
	C1413B	12/8	14		4/10	11		16/0	16	
	C1415A	8/3	9		10/5	11		3/9	9	
15	C1415A	3/1	3	7	2/2	3	4	1/1	1	7
	C1516A	3/6	7		6/2	6		5/6	8	
	C1615A	6/8	10		2/2	3		5/6	8	
16	C1516A	36	7	7	4/0	4	7	2/5	5	7
	C1615A	8/1	8		8/8	11		3/9	9	
	C1617A	0/0	0		6/8	10		5/8	9	
	C1617B	10/7	12		1/0	1		0/5	5	
	C1716A	9/1	9		6/5	8		5/3	6	

Table 8-2 River Verification Data Summary - At Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

		Loran-C vs Miniranger			GPS vs Miniranger			Loran-C vs GPS		
WP	Data File	At/Ct	D	Mean	At/Ct	D	Mean	At/Ct	D	Mean
1	C0102A	12/1	12	12	0/0	0	3	13/3	13	16
	C0201A	13/0	13		5/2	5		18/1	18	
2	C0203A	10/3	10	10	4/2	4	4	13/2	13	12
	C0302A	13/0	13		0/6	6		10/5	11	
	C0102A	5/2	5		0/0	0		8/2	8	
	C0201A	10/3	10		5/1	5		17/0	17	
3	C0304A	11/2	11	14	3/4	5	6	5/5	7	15
	C0403A	15/0	15		10/3	10		21/2	21	
	C0203A	15/7	17		1/10	10		17/3	17	
	C0302A	13/0	13		0/0	0		13/0	13	
4	C0304A	7/8	11	12	5/7	9	5	5/4	6	13
	C0403A	6/5	8		4/0	4		13/3	13	
	C0405A	12/0	12		0/0	0		11/0	11	
	C0504A	17/7	18		5/2	5		21/4	21	
5	C0405A	22/9	24	15	0/9	9	9	22/0	22	19
	C0504A	12/7	14		0/5	5		15/0	15	
	C0506A	8/3	9		3/10	10		13/3	13	
	C0605A	12/0	12		10/4	11		24/3	24	
6	C0506A	8/0	8	10	3/2	4	5	15/3	15	16
	C0605A	5/0	5		7/1	7		10/1	10	
	C0607A	8/0	8		0/0	0		18/0	18	
	C0706A	18/2	18		7/2	7		22/0	22	
7	C0607A	15/0	15	14	0/9	9	9	4/9	10	16
	C0706A	4/5	6		10/2	10		15/4	16	
	C0708A	19/4	19		3/7	8		11/12	16	
	C0807A	14/8	16		2/8	8		13/17	21	
8	C0708A	21/7	22	11	8/11	14	14	11/19	22	19
	C0807A	11/8	14		3/10	10		5/18	19	
	C0809A	0/0	0		17/5	18		12/5	13	
	C0908A	6/6	8		10/8	13		17/15	23	
9	C0809A	3/2	4	5	7/8	11	9	5/4	6	8
	C0908A	1/3	3		5/0	5		7/4	8	
	C0910B	7/5	9		9/3	9		3/6	7	
	C1009A	4/3	5		9/3	9		4/8	9	

8.2 RIVER ROUTE SYSTEM COMPARISONS - AT THE WAYPOINTS

The Along/Cross Track Plot from the analysis of each data run indicates the amount of along track and cross track error at each sampled point along the trackline. We determined the amount of along track error and cross track error at each waypoint (i.e. the ends of the tracklines) from these plots. These At and Ct error values are shown in Table 8-2. Also shown is the composite error (D) for each data run determined by computing the square root of the sum of the squares of the At and Ct errors. The average error is computed for each waypoint based on the composite error for each data run and the average errors of all the waypoints are combined into a single number equal to the mean plus two sigma of the average errors.

Figure 8-4 shows how each system compared to the other systems at the waypoints in the River Route. Although the points are connected with lines, the lines are <u>not</u> meant to indicate the errors between waypoints. They are only shown to identify the three sets of points.

a. <u>Loran-C vs Miniranger</u>. Table 8-2 shows that Loran-C compared within ± 15 meters of Miniranger 95% of the time at the waypoints in the River Route.

b. <u>GPS vs Miniranger</u>. Table 8-2 shows that GPS compared within ± 15 meters of Miniranger 95% of the time at the waypoints in the River Route.

c. <u>Loran-C vs GPS</u>. Table 8-2 shows that Loran-C compared within ± 21 meters of GPS 95% of the time at the waypoints in the River Route.

Figure 8-3

Loran-C vs. GPS, River Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

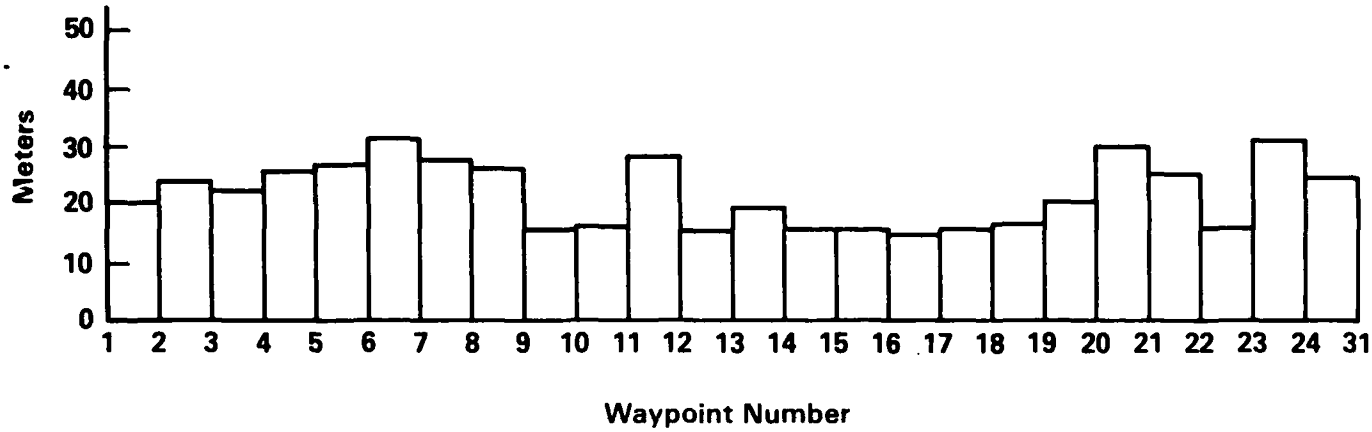


Figure 8-1

Loran-C vs. Miniranger, River Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

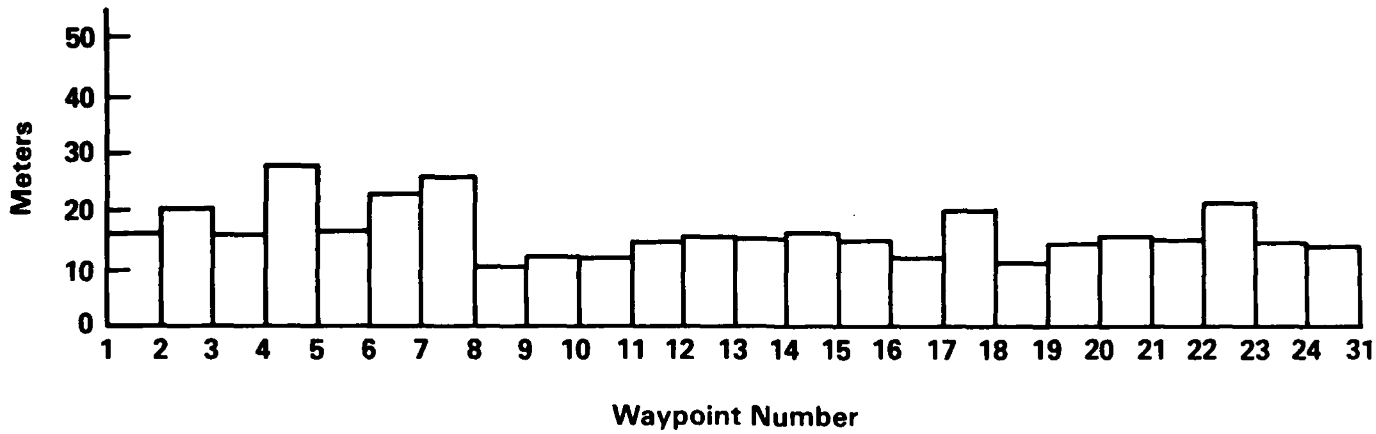


Figure 8-2

GPS vs. Miniranger, River Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

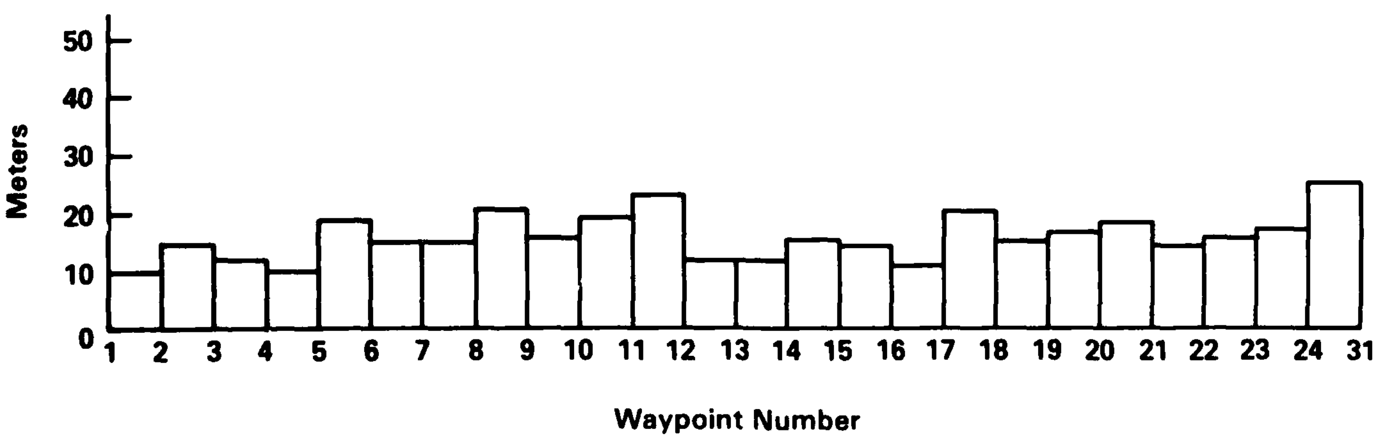


Table 8-1 (continued) River Verification Data Summary

Position Difference Between Systems, In Meters (95%), All Samples.

Data File	Loran-C vs Miniranger	GPS vs Miniranger	Loran-C vs GPS
C1920	14	20	17
C1920A	11	-	-
C1920C	19	14	25
WP19A	11	17	17
C2021C	17	20	30
C2122C	16	14	25
C2223A	17	17	19
C2322A	25	15	14
C2324A	13	17	25
C2423A	18	18	34
C2423B	13	21	30
C2401A	12	26	23
C0124A	17	28	36
Mean	16.4	16.4	21.2
Sigma	5.5	4.7	7.3
Mean + 2 Sigma	27.4 meters	25.8 meters	35.8 meters

Data File Names: nnfftt#

Where: nn is the type of data run: C = centerline run
WP = Waypoint hover

ff is the From waypoint #

tt is the To waypoint #

is the data run #, A is 1st, B is 2nd, etc.

Table 8-1 River Verification Data Summary - All Samples

Position Difference Between Systems, In Meters (95%), All Samples.

Data File	Loran-C vs Miniranger	GPS vs Miniranger	Loran-C vs GPS
C0102A	18	9	20
C0201A	15	10	21
C0203A	20	17	21
C0302A	22	11	27
C0304A	13	14	15
C0403A	20	11	30
C0405A	25	9	21
C0504A	31	11	31
C0506A	17	21	26
C0605A	18	17	30
C0607A	22	11	24
C0706A	25	19	40
C0708A	29	15	31
C0807A	23	16	26
C0809A	8	27	28
C0908A	13	16	27
C0910B	15	14	9
C1009A	10	17	20
C1011A	10	18	19
C1011B	15	19	14
C1110A	10	-	-
C1112A	18	24	39
C1112B	12	22	17
C1213B	14	12	15
C1312A	19	13	14
C1314A	16	14	24
C1314B	11	11	14
C1413A	16	13	17
C1413B	22	13	21
C1415A	17	16	15
C1516A	14	12	15
C1615A	14	16	15
C1617A	7	15	14
C1617B	17	6	14
C1716A	11	13	13
C1718A	19	19	16
C1718C	21	20	13
WP17A	15	25	19
C1817A	13	19	13
C1817C	30	24	15
C1819A	14	15	19
C1819C	10	17	19
WP18A1	7	18	19
WP18A2	12	17	12

8.0 RESULTS

The results of the verification are based on the results of comparing each system to each other system and on the known (confirmed) accuracies of the reference systems.

8.1 RIVER ROUTE SYSTEM COMPARISONS - ALL SAMPLES

Miniranger, Loran-C and GPS were compared against one another in the River verification analysis. The scatter plot from the analysis of each data run indicates the mean plus 2 sigma error, called the 95% confidence figure, between the two systems being compared. We combined the 95% error figures of all analyses by computing the mean and 2 sigma values of the 95% confidence figures. The resulting mean plus 2 sigma value is a measure of the difference measured between the two systems, considering all samples. Table 8-1 shows the position difference figures (in meters, 95%) for each data run and the resulting mean plus 2 sigma values for each of the system comparisons.

a. Loran-C vs Miniranger. Table 8-1 shows that Loran-C compared within ± 27 meters of Miniranger 95% of the time in the River Route. Figure 8-1 is a bar graph showing how Loran-C compared with Miniranger between each waypoint. The mean of the 95% confidence figures is computed and plotted separately for each data run between adjacent waypoints.

b. GPS vs Miniranger. Table 8-1 shows that GPS compared within ± 26 meters of Miniranger 95% of the time in the River Route. Figure 8-2 is a bar graph showing how GPS compared with Miniranger between each waypoint. The mean of the 95% confidence figures is computed and plotted separately for each data run between adjacent waypoints.

c. Loran-C vs GPS. Table 8-1 shows that Loran-C compared within ± 36 meters of GPS 95% of the time in the River Route. Figure 8-3 is a bar graph showing how Loran-C compared with GPS between each waypoint. The mean of the 95% confidence figures is computed and plotted separately for each data run between adjacent waypoints.

As discussed earlier, we collected Raydist verification data only on the Ocean Route. We had frequent Raydist lane slips during data collection. Attempts to re-initialize Raydist using Miniranger positions were sometimes successful but were often closely followed by more lane slips. One attempt was made to re-initialize Raydist using Loran-C to determine the vessel's position within 1/2 Raydist lane width. This attempt was successful, but it too was followed by more Raydist lane slips.

We noted that although our data clearly showed discrete discontinuities caused by Raydist lane slips, the strip chart on the Raydist system did not show discrete discontinuities, but instead showed nearly continuous noise, especially during the latter part of verification.

7.11 VERIFICATION DATA ANALYSIS PROCEDURE

Verification data analysis follows the same procedure as survey data reduction (section 7.7). In the River Route and the Ocean Route to 20 miles off shore, Miniranger was used as the reference system and Loran-C, GPS, and Raydist were each used as the compared system in separate analyses. Also, GPS was used as the reference system in a separate analysis with Loran-C as the compared system in the River Route. GPS was used as the reference system for all analyses of the Ocean Route beyond 20 miles off shore.

Additionally, the difference between the manually collected At/Ct PILOT data and the At/Ct data from the Loran-C data collection system was computed manually. This gives an indication of the performance of PILOT compared to the data collection Loran-C receiver.

7.12 VERIFICATION DATA ANALYSIS COMMENTS

The result of reducing and analyzing the verification data is to confirm the accuracy of the surveyed waypoint data file for Loran-C TDs, to confirm how good GPS is as a reference system in the Ocean Route, and to generate comparison plots for all systems.

improve the Loran-C repeatable accuracy in Charleston, but the improvement probably will not be significant.

The result of reducing and analyzing the survey data is the updated waypoint data file for Loran-C TDs, the comparison plots for the systems measured, and updated PILOT tapes. This is not the final result of the overall survey, however. The survey must be verified.

7.9 VERIFICATION DATA COLLECTION PROCEDURE

The purpose of the verification was to confirm the accuracy of the Loran-C waypoint TDs using independent data sets from those used to determine the Loran-C waypoints. Also, we attempted to collect GPS and Raydist data to determine their accuracy and validity as reference positioning systems.

Verification repeats all of the steps of data collection (section 7.5) with the following modifications and additions.

a. PILOT Data. The PILOT system was operated during verification using the updated PILOT tape. At/Ct readings computed and displayed on the PILOT terminal were recorded manually during verification data collection.

b. Data Collection Runs. With only a limited amount of time available each day, we collected data only along the tracklines and not stationary data at the waypoints, except where we needed more hover data (this occured at several Ocean Route waypoints because we had run out of time due to satellite availability.) The trackline data was sufficient to verify the accuracy of the waypoint data.

7.10 VERIFICATION DATA COLLECTION COMMENTS

We collected Loran-C and Miniranger data as planned on both routes.

We collected GPS data as planned. GPS data collection became especially important since Raydist was not operating reliably. Without a reliable reference system, we could not collect data in the Ocean route beyond the range of our Miniranger equipment, about 20 miles from shore.

The GPS satellites were only available between 2300 and 0300 each day which meant that all verification data collection had to be collected during this time. The remote Miniranger sites were set up before dusk and left operating overnight.

The At/Ct plot also shows if the error increases significantly in the middle of the trackline. If it does (called a "warp" in the trackline), a trackpoint can be added at the point of maximum error. The trackpoint becomes a new waypoint and is treated like all other waypoints in subsequent calculations.

c. Waypoint Move. The waypoint coordinates of the compared system are moved by manually adjusting the current waypoint coordinates in the waypoint file with the delta At and delta Ct values determined in the Compare routine. The adjusted waypoint coordinates are then re-stored in the waypoint file.

d. Miscellaneous. Other optional plots, such as plotting the X/Y or At/Ct data directly (as opposed to difference plots) are available in the data reduction program. They are used infrequently as intermediate steps in analyzing the data and are not critical to the data reduction process.

The updated Loran-C TDs in the waypoint file are combined with the digitized chartlet data (produced during survey planning) resulting in useable PILOT tapes. PILOT tape generation is described in reference 8 and will not be repeated in this report.

7.8 SURVEY DATA REDUCTION COMMENTS

The Loran-C and Miniranger data was reduced in both the River and Ocean Routes according to the above procedure using Miniranger as the reference system and Loran-C as the compared system.

We found that the errors increased when we adjusted the Loran-C data with the 15 minute averaged Loran-C Monitor data. This suggests that the short term (i.e. 15 minute) signal stability is about the same as the long term (i.e. annual) signal stability in Charleston. Said another way, there is no significant seasonal component to the signal stability in Charleston. A seasonal component would be largely due to variations in the propagation speed over land from each of the transmitters. In Charleston, the Y and Z secondary signals are entirely over water. The master signal is over land, but the type of land along this path is probably not subject to large variations in conductivity (it does not usually freeze, for example), and therefore the propagation speed does not vary considerably.

Because of this finding, we decided not to adjust any of the Loran-C survey data with the monitor data. We continued to collect the monitor data for record purposes. Although the 15 minute averages did not work here, realtime differential corrections with different averaging times may

8.3 OCEAN ROUTE SYSTEM COMPARISONS - ALL SAMPLES

Loran-C, Raydist and GPS were compared against Miniranger in the Ocean Route verification analysis out to waypoint 6. Loran-C, Raydist and GPS were compared against one another in the Ocean Route verification analysis for all waypoints. The scatter plot from the analysis of each data run indicates the mean plus 2 sigma error, called the 95% confidence figure, between the two systems being compared. We combined the 95% error figures of all analyses by computing the mean and 2 sigma values of the 95% confidence figures. The resulting mean plus 2 sigma value is a measure of the difference measured between the two systems, considering all samples.

Table 8-3 shows the position difference figures (in meters, 95%)for each data run, and the resulting mean plus 2 sigma values for each of the system comparisons where Miniranger was used as the reference.

Table 8-4 shows the position difference figures for each data run and the resulting mean plus 2 sigma values for each of the system comparisons where GPS was used as the reference.

a. Loran-C vs Miniranger. Table 8-3 shows that Loran-C compared within ± 26 meters of Miniranger 95% of the time in the Ocean Route. Figure 8-5 is a bar graph showing how Loran-C compared with Miniranger between each waypoint.

b. GPS vs Miniranger. Table 8-3 shows that GPS compared within ± 24 meters of Miniranger 95% of the time in the Ocean Route. Figure 8-6 is a bar graph showing how GPS compared with Miniranger between each waypoint.

c. Raydist vs Miniranger. Table 8-3 shows that Raydist compared within ± 121 meters of Miniranger 95% of the time in the Ocean Route. This includes only data runs that did not have large Raydist lane slips. Figure 8-7 is a bar graph showing how Raydist compared with Miniranger between each waypoint.

d. Loran-C vs GPS. Table 8-4 shows that Loran-C compared within ± 30 meters of GPS 95% of the time in the Ocean Route. This does not include the data run when GPS was in a sub-optimal mode. Figure 8-8 is a bar graph showing how Loran-C compared with GPS between each waypoint.

e. Raydist vs GPS. Table 8-4 shows that Raydist compared within ± 107 meters of GPS 95% of the time in the Ocean Route. This includes only data runs that did not have large Raydist lane slips, and does not include the data run when GPS was in a sub-optimal mode. Figure 8-9 is a bar graph showing how Raydist compared with GPS between each waypoint.

Table 8-3 Ocean Verification Data Summary - All Samples, Miniranger as Reference

Position Difference Between Systems, In Meters (95%), All Samples.

Data File	Loran-C vs Miniranger	GPS vs Miniranger	Raydist vs Miniranger
C0104A	15	22	48*
C0401A	21	17	250**
C0406A	22	24	86*
C0604A	21	13	314**
Mean	19.8	18.4	67.0*
Sigma	3.2	3.0	26.9*
Mean + 2 Sigma	26.2 meters	24.4 meters	120.7* meters

* These data runs occurred before a large Raydist lane slip

** These data runs occurred after a large Raydist lane slip

Data File Names: nnfftt#

Where: nn is the type of data run: C = centerline run
WP = Waypoint hover

ff is the From waypoint #

tt is the To waypoint #

\# is the data run #, A is 1st, B is 2nd, etc.

Table 8-4 Ocean Verification Data Summary - All Samples, GPS as Reference

Position Difference Between Systems, In Meters (95%), All Samples.

Data File	Loran-C vs GPS	Raydist vs GPS
C0104A	20	62*
C0401A	16	241**
C0406A	16	92*
C0604A	22	325**
C0609A	43***	211***
C0912A	19	325**
C1215A	21	1502**
C1517A	22	1706**
C1618A	30	60****
Mean	20.8	71.3#
Sigma	4.4	17.9#
Mean + 2 Sigma	29.6 meters	107.2# meters

* These data runs occurred before a large Raydist lane sl p

** These data runs occurred after a large Raydist lane slip

*** Sub-optimal GPS position due to problem in GPS almanac. Not used for statistical calculations.

**** This data run occurred after Raydist was re-initialized with Loran-C

\# Mean and Sigma include only * and **** data runs.

Data File Names: nnfftt#

Where: nn is the type of data run: C = centerline run
WP = Waypoint hover

ff is the From waypoint #

tt is the To waypoint #

\# is the data run #, A is 1st, B is 2nd, etc.

Figure 8-5

Loran-C vs. Miniranger, Ocean Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

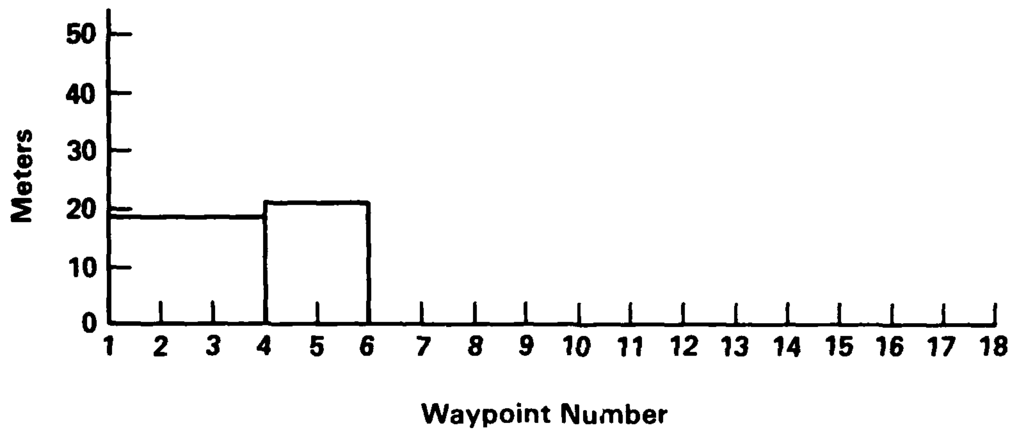


Figure 8-6

GPS vs. Miniranger, Ocean Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

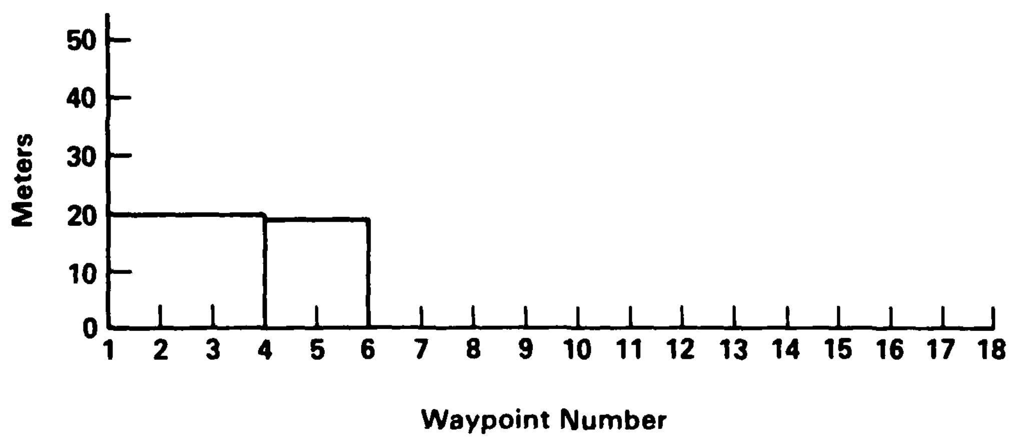


Figure 8-7

Raydist vs. Miniranger, Ocean Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

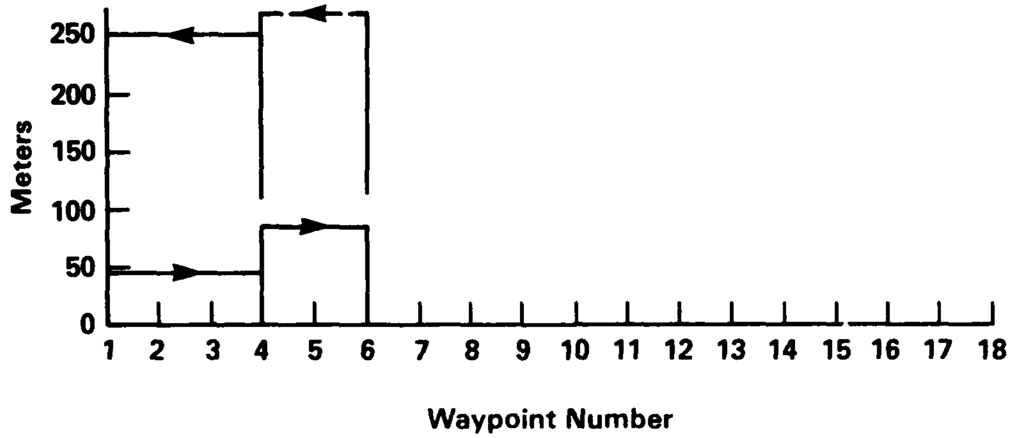


Figure 8-8

Loran-C vs. GPS, Ocean Route - Comparison of Means of 95% Confidence Figures Between Waypoints.

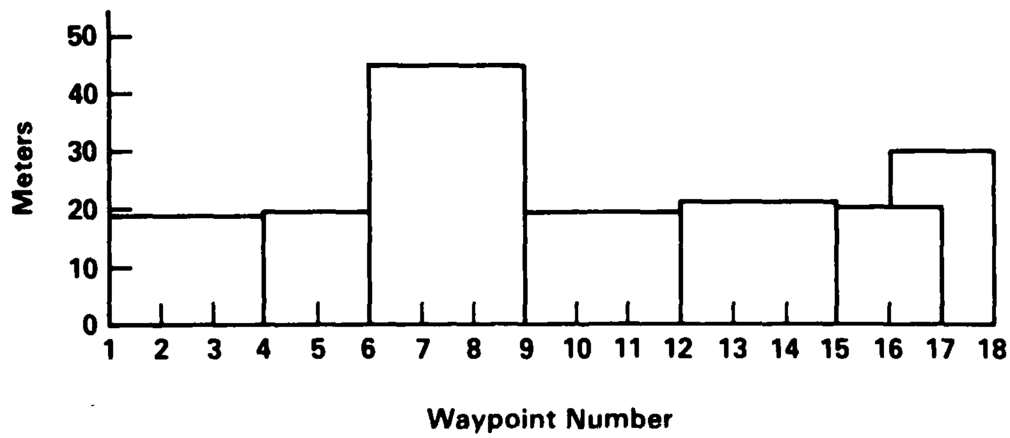
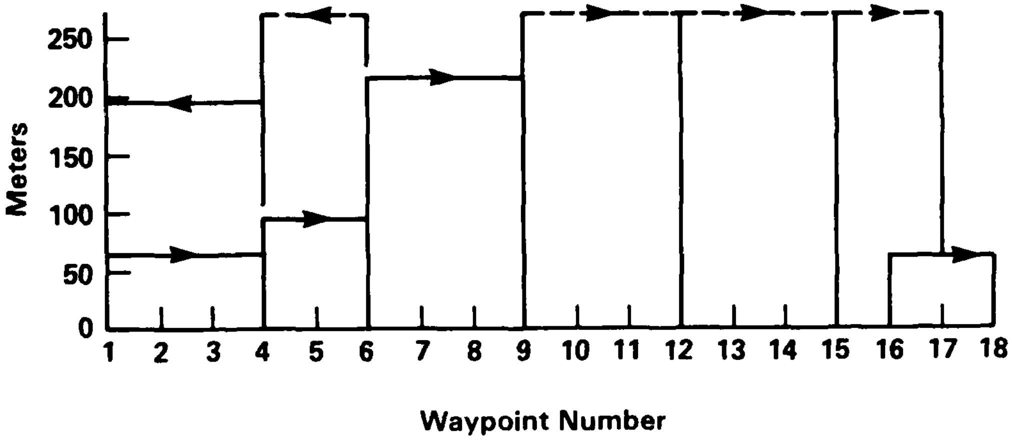


Figure 8-9

Raydist vs. GPS, Ocean Route - Comparison of Means of 95% Confidence Figures Between Waypoints.



8.4 OCEAN ROUTE SYSTEM COMPARISONS - AT THE WAYPOINTS

Table 8-5 shows the At and Ct error values and the composite error for each Ocean verification data run where Miniranger was used as the reference. The average error is computed for each waypoint based on the composite error for each data run, and the average errors of all the waypoints are combined into a single number equal to the mean plus two sigma of the average errors.

Table 8-6 shows the At and Ct error values and the composite and average errors for each Ocean verification data run where GPS was used as the reference.

Figure 8-10 shows how Loran-C and GPS compared to Miniranger and how Loran-C compared to GPS at the waypoints in the Ocean Route. Figure 8-11 shows how Raydist compared to both Miniranger and GPS. Note where Raydist lane slips are evident and where Loran-C was successfully used to re-initialize Raydist. Also note where GPS was providing a sub-optimal solution due to a problem with the almanac.

Although the points in both figures are connected with lines, the lines are not meant to indicate the errors between waypoints. They are only shown to identify the various sets of points.

a. Loran-C vs Miniranger. Table 8-5 shows that Loran-C compared within ± 21 meters of Miniranger 95% of the time at the waypoints in the Ocean Route.

b. GPS vs Miniranger. Table 8-5 shows that GPS compared within ± 18 meters of Miniranger 95% of the time at the waypoints in the Ocean Route.

c. Raydist vs Miniranger. Table 8-5 shows that Raydist compared within ± 88 meters of Miniranger 95% of the time at the waypoints in the Ocean Route. This includes only data runs that did not have large Raydist lane slips.

d. Loran-C vs GPS. Table 8-6 shows that Loran-C compared within ± 20 meters of GPS 95% of the time at the waypoints in the Ocean Route. This does not include the data when GPS was in a sub-optimal mode.

e. Raydist vs GPS. Table 8-6 shows that Raydist compared within ± 91 meters of GPS 95% of the time at the waypoints in the Ocean Route. This includes only data runs that did not have large Raydist lane slips, and does not include the data when GPS was in a sub-optimal mode.

Table 8-5 Ocean Verification Data Summary, with Miniranger as the Reference - At the Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

WP	Data File	Loran-C vs Miniranger At/Ct	D	Mean	GPS vs Miniranger At/Ct	D	Mean	Raydist vs Miniranger At/Ct	D	Mean
1	C0104A	7/1	7	10	10/9	13	14	6/32	33	33*
	C0401A	13/2	13		8/11	14		130/148	197	197**
2	C0104A	2/13	13	15	0/13	13	14	15/32	35	48*
	C0401A	0/17	17		7/12	14		153/162	223	223**
3	C0104A	4/9	10	13	0/16	16	13	22/33	40	40*
	C0401A	0/15	15		0/9	9		160/169	223	223**
4	C0104A	2/8	8	13	4/9	10	11	28/32	43	56*
	C0406A	1/13	13		2/17	17		30/61	68	
	C0401A	4/16	16		0/9	9		163/182	244	243**
	C0604A	4/13	14		3/9	9		120/210	242	
5	CO406A	0/11	11	10	8/11	14	9	35/59	69	69*
	C0604A	0/8	8		3/3	4		149/228	267	267**
6	C0406A	18/15	23	20	22/3	22	16	39/67	78	78*
	C0604A	12/12	17		6/8	10		184/240	287	287**
Mean				13.5			12.8			54.0*
Sigma				3.7			2.5			17.2*
Mean + 2 Sigma				21.0 meters			17.8 meters			88.4*

* These data runs occurred before a large Raydist lane slip

** These data runs occurred after a large Raydist lane slip

Table 8-6 Ocean Verification Data Summary, with GPS as the Reference - At the Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

WP	Data File	Loran-C vs GPS At/Ct	D	Mean	Raydist vs GPS At/Ct	D	Mean
1	C0104A	1/10	10	13	15/40	43	43*
	C0401A	15/4	16		156/140	210	210*
2	C0104A	4/0	4	8	18/45	48	48*
	C0401A	8/8	11		158/147	216	216**
3	C0104A	7/6	9	8	24/49	55	55*
	C0401A	2/6	6		158/155	221	221**
4	C0104A	0/2	2	6	22/45	50	57*
	C0406A	7/1	7		35/52	63	
	C0401A	3/7	8		169/166	237	237**
	C0604A	3/5	6		118/204	236	
5	C0406A	9/2	9	7	42/55	69	69*
	C0604A	2/5	5		150/220	266	266**
6	C0406A	2/12	12	11	50/61	79	79*
	C0604A	8/16	10		190/247	312	312**
	C0609A	7/37	38	38***	12/120	121	121***
7	C0609A	8/25	26	26***	0/171	171	171***
8	C0609A	14/19	24	24***	98/47	109	109***
9	C0609A	21/11	24	24***	115/41	122	122***
	C0912	5/5	7	7	117/70	136	136
10	C0912A	12/3	12	12	153/50	161	161
11	C0912A	7/11	13	13	40/219	223	223
12	C0912A	0/7	7	9	70/240	250	241
	C1215A	11/0	11		65/225	234	
13	C1215A	5/3	6	6	83/238	252	252
14	C1215A	4/2	4	4	BIG	BIG	BIG

Table 8-6 (continued) Ocean Verification Data Summary, with GPS as the Reference - At the Waypoints

Position Difference Between Systems, In Meters (95%), at Waypoint Positions.

		Loran-C vs GPS			Raydist vs GPS		
WP	Data File	At/Ct	D	Mean	At/Ct	D	Mean
15	C1215A	13/0	13	11	BIG	BIG	BIG
	C1517A	9/0	9		BIG	BIG	BIG
16	C1517A	11/0	11	15	BIG	BIG	BIG
	C1618A	13/15	20		23/4	23	23****
17	C1618A	11/17	20	20	8/3	9	9****
18	C1618A	12/17	21	21	48/18	51	51****
Mean				10.7			48.2#
Sigma				4.9			21.5#
Mean + 2 Sigma				20.5 meters			91.3# meters

* These data runs occurred before a large Raydist lane slip

** These data runs occurred after a large Raydist lane slip

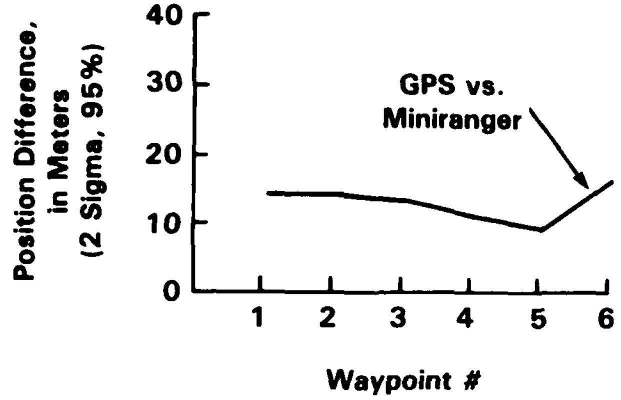
*** Sub-optimal GPS solution due to problem in GPS almanac

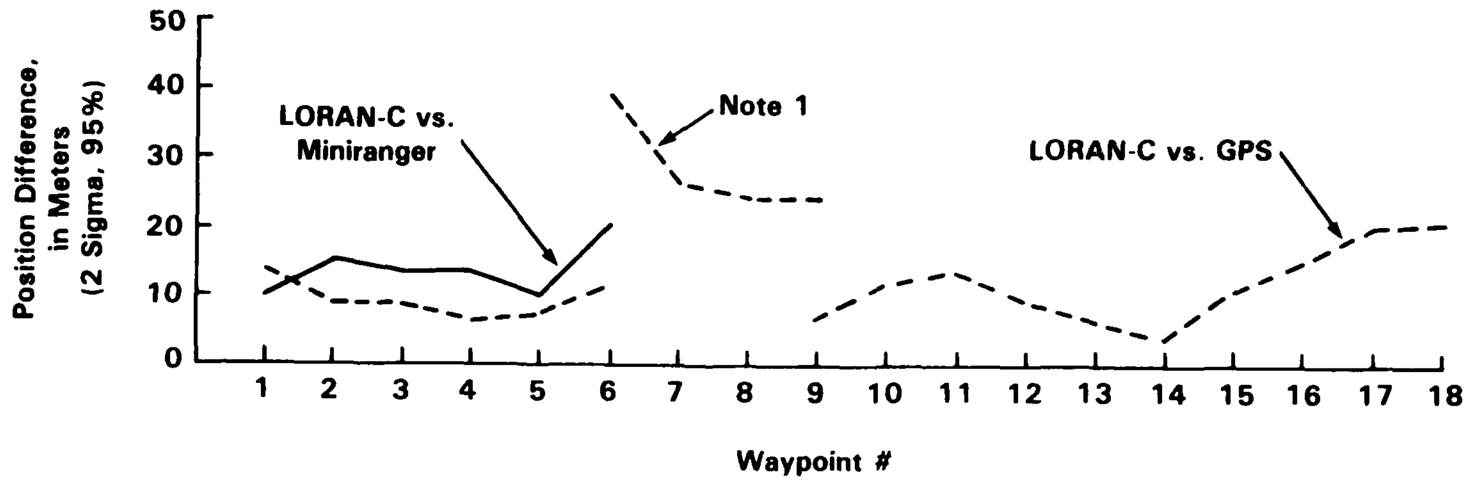
**** This data run occurred after Raydist was re-initialized with Loran-C

BIG means position difference was greater than 350 meters

\# Mean and Sigma includes only * and **** data runs

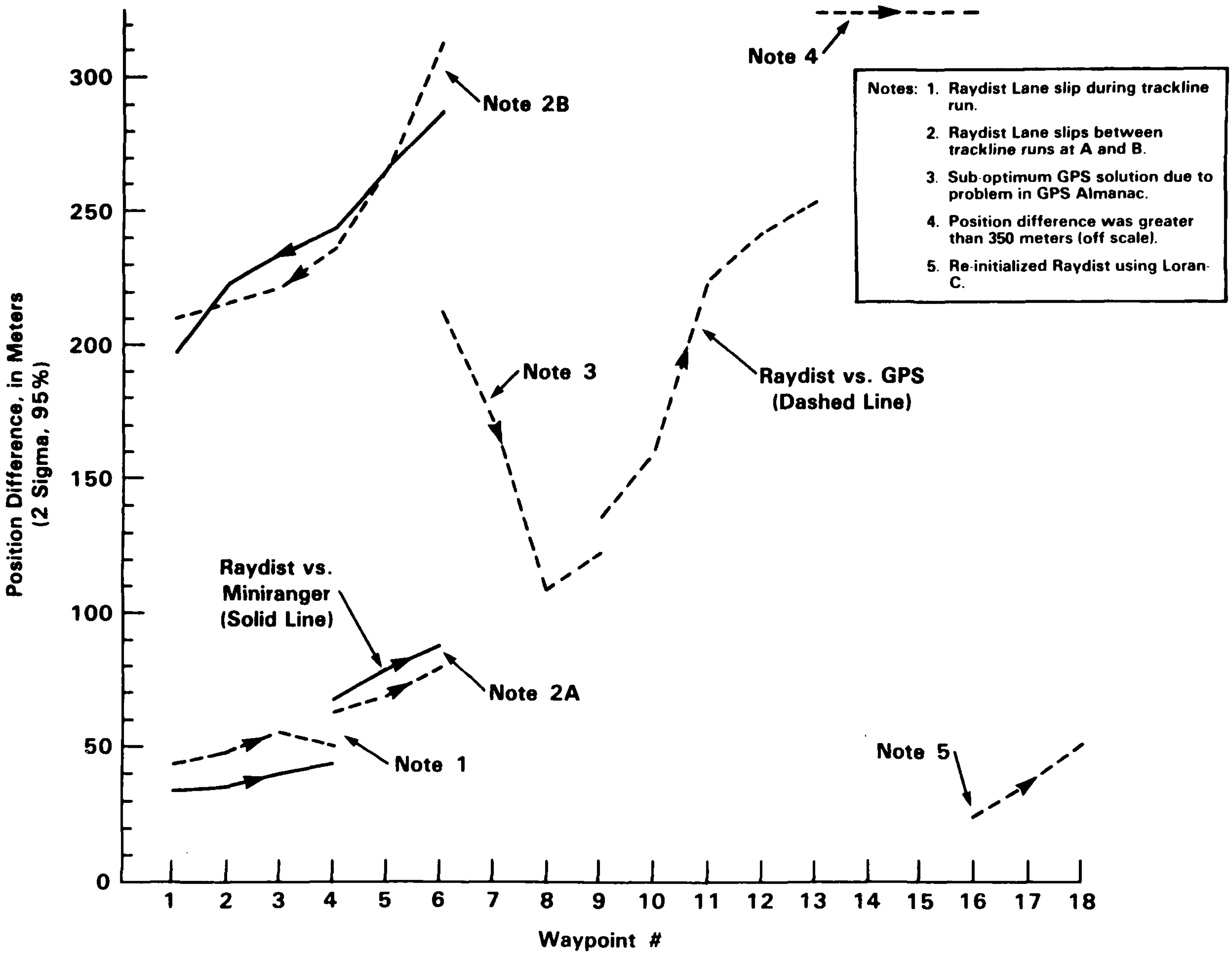
Waypoint Position Comparisons: Ocean Route





Note 1: Sub-Optimum GPS Solution Due to Problem in GPS Almanac.

Ocean Route



Position Difference, in Meters (2 Sigma, 95%)
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Waypoint #
Note 1
Note 2A
Note 2B
Note 3
Note 4
Note 5
Raydist vs. Miniranger (Solid Line)
Raydist vs. GPS (Dashed Line)
Notes: 1. Raydist Lane slip during trackline run.
2. Raydist Lane slips between trackline runs at A and B.
3. Sub-optimum GPS solution due to problem in GPS Almanac.
4. Position difference was greater than 350 meters (off scale).
5. Re-initialized Raydist using Loran-C.

8.5 SUMMARY OF SYSTEM COMPARISONS

Table 8-7 summarizes the position difference comparisons between the various systems.

As table 8-7 shows, Loran-C compared very favorably with Miniranger positions both in the River and Ocean Routes. Also, GPS performed almost identically as Loran-C when compared to Miniranger. The Loran-C vs GPS figures are only slightly larger then the Loran-C vs Miniranger figures. This suggests that GPS performed well as a reference positioning system, although not quite as well as Miniranger.

The Raydist vs Miniranger and Raydist vs GPS figures are similar, again suggesting that GPS is almost as good a reference positioning system as Miniranger. More importantly, Raydist performed worse than our expectations. The numbers in Table 8-7 for Raydist are for the periods of best operation we observed during the survey. Had we included in the computations those data runs with large Raydist lane slips, the summary position difference figures for Raydist would have been worse.

8.6 BRIDGE EFFECTS

Prior studies and surveys have shown that Loran-C signals are distorted by bridges, powerlines, and large metal structures. The only anomaly we encountered in Charleston was the Cooper River Bridge. Beginning approximately 300 meters from the bridge, the Loran-C positions diverged from the actual geodetic positions, reaching a maximum under the bridge of 60 meters along track error and 25 meters cross track error, compared to Miniranger. This translates to a position error of:

$$\sqrt{60^2 + 25^2} = 65 \text{ meters position error}$$

We did not include the parts of the tracklines that were affected by the bridge in our data reductions or in the summary position error figures. Also, we made no attempt to compensate for the bridge effect (e.g. adding multiple waypoints under and near the bridge) because the length of the problem area is relatively short. We feel it is reasonable for a vessel to navigate by other means in this section when the Loran-C positions are unuseable.

CHARLESTON, SC

HHE SURVEY

APRIL-JULY 1983

SURVEYED WAYPOINTS

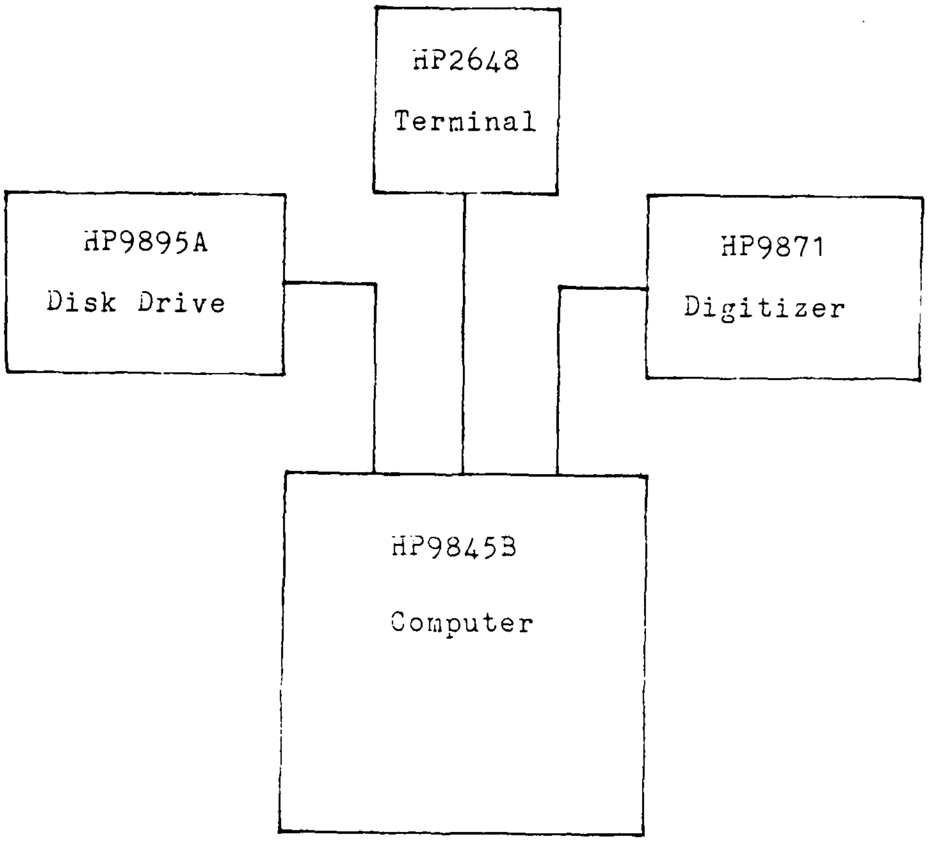
RIVER ROUTE

	State Plane Coordinates (SC South)		NAD-27 Geodetic Coordinates		Loran-C 7980	
P	X	Y	Latitude	Longitude	MY	MZ
1	707735	119798	32°54'33.30"	79°57'03.35"	45581.93	60511.06
2	707494	119490	32°54'23.38"	79°57'12.72"	45582.02	60513.41
3	706631	118458	32°53'50.13"	79°57'46.33"	45582.54	60521.78
4	706283	117106	32°53'06.37"	79°58'00.23"	45580.78	60527.99
5	706247	116481	32°52'46.10"	79°58'01.85"	45579.59	60530.25
6	706578	115369	32°52'09.90"	79°57'49.54"	45576.32	60531.87
7	707066	114507	32°51'41.74"	79°57'31.08"	45573.08	60531.92
8	707206	114344	32°51'36.39"	79°57'25.75"	45572.32	60531.68
9	707795	113898	32°51'21.74"	79°57'03.30"	45569.62	60529.66
0	709421	113311	32°51'02.15"	79°56'00.98"	45563.50	60522.13
1	709853	112730	32°50'43.15"	79°55'44.58"	45560.97	60521.51
2	709923	112414	32°50'32.87"	79°55'42.01"	45560.08	60522.12
3	709734	110486	32°49'30.34"	79°55'50.06"	45556.61	60529.40
4	709833	110050	32°49'16.16"	79°55'46.41"	45555.37	60530.24
5	710142	109757	32°49'06.54"	79°55'34.66"	45553.81	60529.40
6	711181	109206	32°48'48.30"	79°54'54.92"	45549.47	60525.19
7	711297	108947	32°48'39.87"	79°54'50.57"	45548.58	60525.38
8	710967	107088	32°47'39.63"	79°55'03.99"	45545.65	60533.35
9	711052	106299	32°47'13.97"	79°55'01.04"	45543.70	60535.47
0	711495	105651	32°46'52.79"	79°54'44.25"	45540.93	60535.02
1	711962	105354	32°46'42.99"	79°54'26.44"	45538.88	60533.28
2	712950	105210	32°46'38.01"	79°53'48.53"	45535.55	60528.07
3	715778	103180	32°45'31.11"	79°52'00.71"	45522.56	60518.46
4	717759	101044	32°44'21.09"	79°50'45.50"	45512.00	60514.19
1	732479	92989	32°39'54.00"	79°41'24.00"	45450.17	60458.92

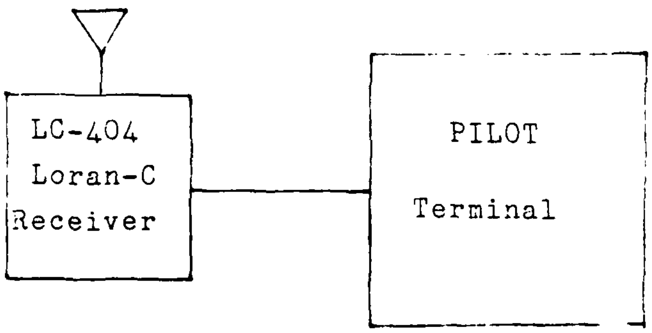
OTE: State Plane Coordinates are in Meters
Latitudes are North
Longitudes are West
Loran-C TDs are in microseconds

APPENDIX C

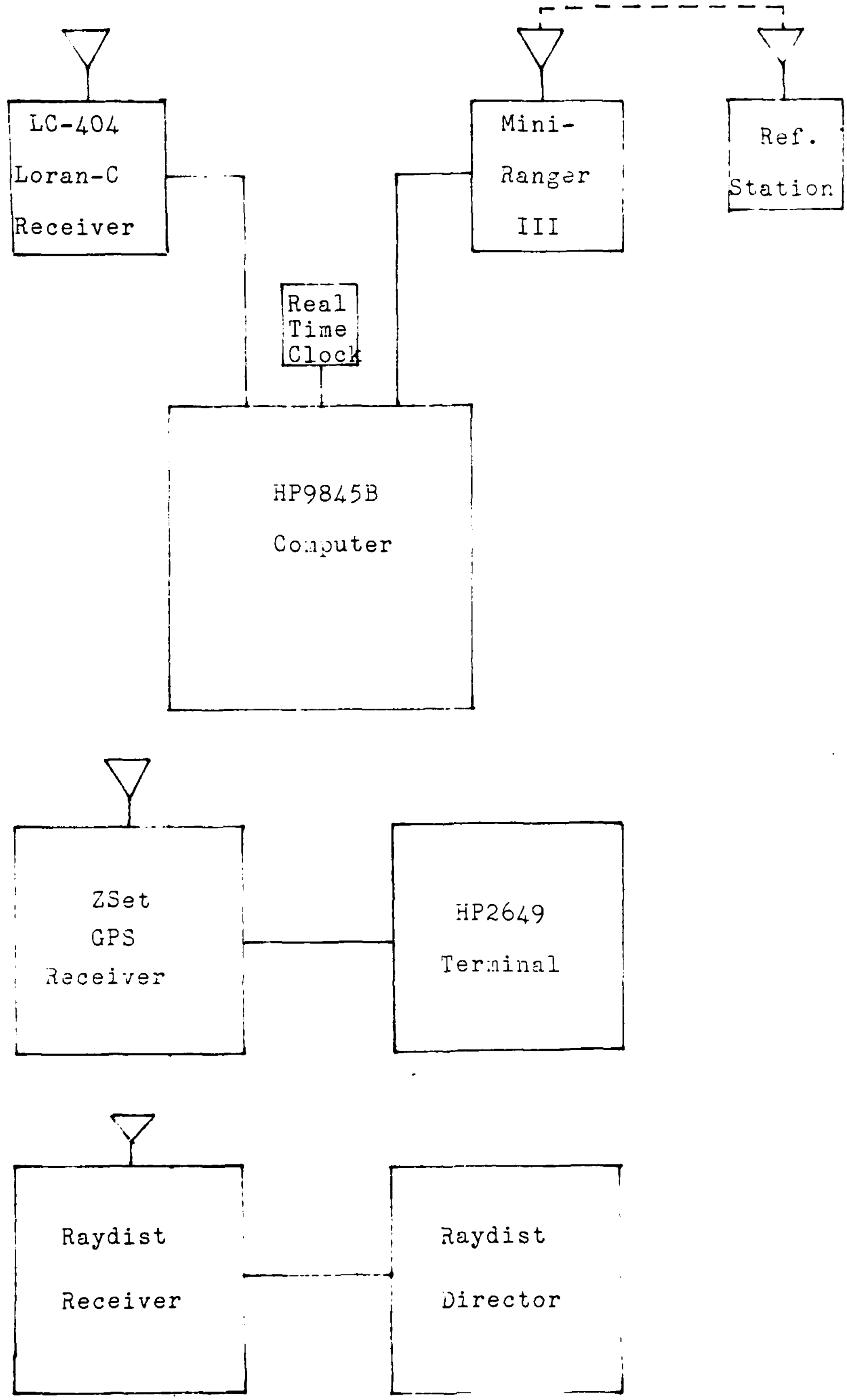
RIVER ROUTE SURVEYED WAYPOINT LISTS



Data Reduction and PILOT Tape
Generation System



PILOT System



Data Collection System

APPENDIX B

SYSTEM INTERCONNECT DIAGRAMS

b. USN

1. COMINEWARCOM
   CDR Ross Bell, COMINEWARCOM Staff Navy Base, Charleston, S.C. (803) 743-4218.

2. COMINEGRU2
   CDR Leslie W. Hewett, Chief Staff Officer, Mine Group 2 U.S. Navy Base, Charleston, S.C. (803) 743-3916.

3. COMINEDIV125
   LCDR Robert S. Rawls, Commodore Mine Division 125, U.S. Navy Base, Charleston, S.C. (803) 743-4733.

V. Amendment and Termination

a. This Agreement may be amended or terminated by mutual agreement of the signatories.

b. This document, upon acceptance by the authorized representatives of the United States Coast Guard and the United States Navy, constitutes an Agreement between the two parties.

Acceptance

United States Coast Guard

R.A. BAUMAN
Name

Chief, Office of Navigation
Title

R.A. Bauman
Signature

5/9/83
Date

United States Navy

RADM C.F. HORNE III
Name

Commander, Mine Warfare Command
Title

C.F. Horne III
Signature

5/13/83
Date

United States Navy

CAPT W.A. HERMAN
Name

Commander, Mine Group 2
Title

W.A. Herman
Signature

5/12/83
Date

United States Navy

LCDR R.S. RAWLS
Name

Commodore, Mine Division 125
Title

R.S. Rawls
Signature

5/11/83
Date

3. The USCG will provide personnel and equipment to support a demonstration of the surveyed routes and using the PILOT system. This demonstration will be performed on a USN provided platform and will occur following completion of the survey. This demonstration is tentatively scheduled for mid-June 1983 and will encompass the Cooper River Route and the Oceanic Route.

b. U.S. NAVY

1. COMINEWARCOM will:

a. Provide a KA-18 RAYDIST Director System.

b. Provide a secure area for processing and storing classified material.

c. Insure the transfer of funds totaling $15K to support rental of a Navigational Positioning System and partial operational costs associated with this Agreement.

2. COMINEGRU2 will:

a. Provide personnel to install and verify operation of the KA-18 RAYDIST Director System.

b. Provide operational assistance for the RAYDIST System if required.

3. COMINEDIV125 will:

a. Provide watercraft (diver boat and ZODIAK) and operators for route survey and demonstration of the Cooper River Route.

b. Provide a platform (LCU) for use during the route survey and demonstration of both the Oceanic Route and the Cooper River Route.

c. Provide base materiel support, if requested.

4. USN will pay for all operational costs of operating their vessels.

IV. Implementation

For the purpose of implementing this Agreement on a day-to-day basis, the following persons are designated as central points of contact for each Agency:

a. USCG

1. LCDR Richard A. Kirkman, Radionavigation Division, Office of Navigation, USCG Headquarters, (202) 472-5857.

INTERAGENCY AGREEMENT BETWEEN THE UNITED STATES COAST GUARD AND THE UNITED STATES NAVY

Precision Loran-C Navigation System For The Charleston Harbor Area

I. Scope and Purpose

This Agreement addresses the roles and responsibilities undertaken by the U.S. Coast Guard (USCG) and U.S. Navy (USN) in conducting in providing a route survey and demonstration of precision Loran-C navigation in the Charleston area during May through June 1983.

II. Background

Commander, Mine Warfare Command (COMINEWARCOM) initially requested that the USCG provide a demonstration of precision Loran-C navigation in an area from the Charleston Seabuoy to the seaward end of the "Q" route (heareafter referred to as the Oceanic Route). This route involves a distance of approximately 52 nautical miles. Secondly, Commander, Mine Group 2 (COMINEGRU2) and Commander, Mine Division 125 (COMINEDIV125) requested that this demonstration include an area from Buoy 62 near the Charleston Navy Base ordinance reach to the Charleston Seabuoy (hereafter referred to as the Cooper River Route). This route involves a distance of approximately 21 nautical miles. An accuracy of ±100 feet is desired. These demonstrations are scheduled for mid-June 1983. The route survey and demonstration will be conducted using the Precision Intracoastal Loran Translocater (PILOT) system developed by the USCG.

III. Responsibilities

Under this Agreement, the responsibilities of the USCG and USN are as specified below:

a. U.S. COAST GUARD

1. The USCG will supply equipment and personnel to perform a Loran-C survey for the Cooper River Route and the Oceanic Route. This survey is to be accomplished during 10 May to 15 June 1983.

2. The USCG will provide the following:

a. Definition of waypoints.

b. Positions in:

State Plane Coordinates (SC South)
Latitude/Longitude in NAD-27 datum
Loran-C Time Difference (TD) Readings
Raydist Lane Count at the waypoints

c. Comparison Plots between Mini-Ranger, Loran-C, Raydist and NAVSTAR GPS data.

APPENDIX A

INTERAGENCY AGREEMENT

unrealistic for most precise navigation applications. We had some difficulty in achieving good initialization accuracy under excellent conditions (ship anchored in calm seas using Miniranger as the reference positioning system). A stationary initialization point does not exist in Charleston (although one could be built), and we believe that using a buoy position does not yield sufficient accuracy due to the tidal and weather effects on the buoy. For vessels approaching the seaward end of a channel, a stationary initialization point there is not feasable due to water depth. Although we successfully re-initialized Raydist using Loran-C near the 100 fathom curve (once), the same could not be done for first time initialization. The numerous lane slips we observed further reduced our confidence in Raydist. A lane slip when a vessel is transiting a very restricted channel could be disasterous.

All of the deliverable items (section 2.2) have been presented in this report except for the Raydist lane counts at the waypoints. We were unable to determine the lane count values due to the problems we had with the Raydist system.

9.0 CONCLUSIONS

Our goal was to demonstrate that Loran-C could provide a repeatable navigational accuracy of ± 100 feet (i.e. ± 31 meters) along both the River and Ocean Routes. We achieved this goal for the entire River Route and the Ocean Route to 20 miles offshore. The main reason we did not achieve this goal beyond 20 miles is that the reference positioning system we used for this part of the survey (GPS) was a less accurate system than the system we used for the rest of the survey (Miniranger). However, we feel that, overall, we successfully demonstrated the precision use of Loran-C in the Charleston area.

We conducted a short demonstration of our results using the PILOT system at the conclusion of the survey. The PILOT system was developed strictly for demonstrating the concept of precision Loran-C and therefore only prototype equipment exists; Development of PILOT is completed. There are, however, Loran-C receivers on the market that have waypoint navigation computers built-in that can make use of the surveyed waypoint positions resulting from a survey like this. Among the parameters that a waypoint navigating receiver should have are:

a. Capability of storing 50 to 100 waypoints.
b. Ten nanosecond measurement and display resolution.
c. Cross/along track indicators in convenient units such as feet, meters, or yards (NOT tenths of miles).
d. Steering indicator.
e. Optional display of position on chart or CRT.

We were favorably impressed with the operation and performance of the GPS system. Although the GPS constellation during the survey provided less accuracy and was less available than the Miniranger system, we feel that GPS served as a good reference positioning system for this survey. Once it is fully developed, GPS should provide sufficient geodetic accuracy to be used for waypoint navigation without the need for surveys such as this. However, Loran-C will still be extremely valuable as a backup to the future GPS system.

As an interim solution, we believe Loran-C in the repeatable mode is an excellent navigation system for waypoint navigation. The chief drawback is that a precision survey must be done for each area of use. The results will depend on the stability and strength of the signals and on the Loran-C geometry in the given area. As waypoint navigation becomes more popular and better understood we expect more and better commercial equipment to become available, and perhaps services such as surveying and signal monitoring to also become commercially available.

We were disappointed in the performance and operation of the Raydist system. The system was, in general, unreliable. We feel that the basic concept of initialization/re-initialization is

Table 8-8 Loran-C Geodetic Accuracies

LOCATION	ACCURACY $\pm$ meters 95%	REFERENCE POSITIONING SYSTEM
River Route	29	Miniranger
Ocean Route to 20 Miles	28	Miniranger
Ocean Route Beyond 20 Miles	36	GPS

8.7 GEODETIC ACCURACY

We found that the Miniranger range accuracy was ± 2 meters or better as advertised. The position accuracy from two ranges with crossing angles between 30 and 150 degrees is therefore ± 10 meters. We used this figure to adjust the system comparison figures to get geodetic accuracy figures for each of the systems that used Miniranger as a reference.

We found that GPS performed in the expected 20 to 30 meter accuracy range compared to Miniranger. We therefore used ± 20 meters as the GPS geodetic accuracy figure for adjusting the system comparison figures when GPS was used as a reference.

We computed the root-sum-square of the system comparison figure and its reference system geodetic accuracy figure to arrive at a figure which represents the geodetic accuracy of the compared system. For example, in the River Route:

Loran-C vs Miniranger = ± 27 meters (from Table 8-7 a.)

Miniranger Accuracy = ± 10 meters

$$\text{Loran-C Accuracy} = \sqrt{27^2 + 10^2} = \pm 29 \text{ meters.}$$

Thus, the Loran-C geodetic accuracy in the Charleston River Route using Loran-C in its repeatable mode with surveyed waypoints is ± 29 meters. Since this figure is based on All Samples, it is an overall statement of Loran-C accuracy on this route.

Table 8-8 shows the Loran-C geodetic accuracies achieved for all routes during the Charleston survey. They are computed in the same way as described above.

8.8 SURVEYED WAYPOINT POSITIONS

The surveyed waypoint Loran-C TDs and geodetic positions for the River Route are shown in Appendix C. The surveyed waypoints for the Ocean Route are contained in Supplement C1.

Table 8-7 Summary of Position Differences Between Systems

Position Difference, in meters (95%)

	GPS vs Miniranger	Loran-C vs Miniranger	Loran-C vs GPS
Waypoint Positions	15	15	21
All Samples	26	27	36

a. River Route

	GPS vs Miniranger	Loran-C vs Miniranger	Raydist vs Miniranger
Waypoint Positions	18	21	88
All Samples	24	26	121

b. Ocean Route to 20 Miles Off Shore

	Loran-C vs GPS	Raydist vs GPS
Waypoint Positions	20	91
All Samples	30	107

c. Ocean Route

CHARLESTON, SC

HHE SURVEY

APRIL-JULY 1983

SURVEYED WAYPOINTS

RIVER ROUTE

(CONTINUED)

	WGS-72 Geodetic Coordinates	
WP	Latitude	Longitude
1	32°54'33.84"	79°57'03.06"
2	32°54'23.92"	79°57'12.43"
3	32°53'50.67"	79°57'46.04"
4	32°53'06.92"	79°57'59.94"
5	32°52'46.65"	79°58'01.56"
6	32°52'10.45"	79°57'49.25"
7	32°51'42.29"	79°57'30.79"
8	32°51'36.94"	79°57'25.46"
9	32°51'22.29"	79°57'03.01"
10	32°51'02.70"	79°56'00.69"
11	32°50'43.70"	79°55'44.29"
12	32°50'33.42"	79°55'41.72"
13	32°49'30.89"	79°55'49.77"
14	32°49'16.71"	79°55'46.12"
15	32°49'07.09"	79°55'34.37"
16	32°48'48.85"	79°54'54.63"
17	32°48'40.42"	79°54'50.28"
18	32°47'40.18"	79°55'03.70"
19	32°47'14.52"	79°55'00.75"
20	32°46'53.34"	79°54'43.96"
21	32°46'43.54"	79°54'26.15"
22	32°46'38.56"	79°53'48.24"
23	32°45'31.67"	79°52'00.41"
24	32°44'21.65"	79°50'45.20"
31	32°39'54.56"	79°41'23.68"

NOTE: Latitudes are North
Longitudes are West

APPENDIX D

HORIZONTAL CONTROL SITES

HORIZONTAL CONTROL SITES

CHARLESTON, SC

Site	State Plane Coordinates (SC South) in KM X	Y
Bull	739.294	119.905
Castle	711.629	104.837
Charleston Light	717.974	103.102
Crab	713.811	105.513
Creek	707.732	119.798
Dike	710.219	110.516
Folly Beach Loran Twr	713.926	94.868
Foxtrot	706.860	114.590
FL46A	710.022	110.230
FL52	707.432	114.436
FL58	706.774	118.325
Francis Marion Hotel	709.195	106.112
Goose USE	708.513	119.405
Johnson USE	712.895	102.357
Moultrie 2	716.505	103.137
Mound	709.268	112.685
Naval	708.072	114.427
New	709.871	113.631
November	708.240	113.579
Paul J	710.293	112.460
Project	707.383	119.493
Remley	711.931	109.137
Skippy	710.066	113.291
Uniform	709.263	113.162
Wood Stand	706.855	116.399

Note: The above positions are the ones actually used. Some were "surveyed in", and others were offset from established HC sites by measured amounts.

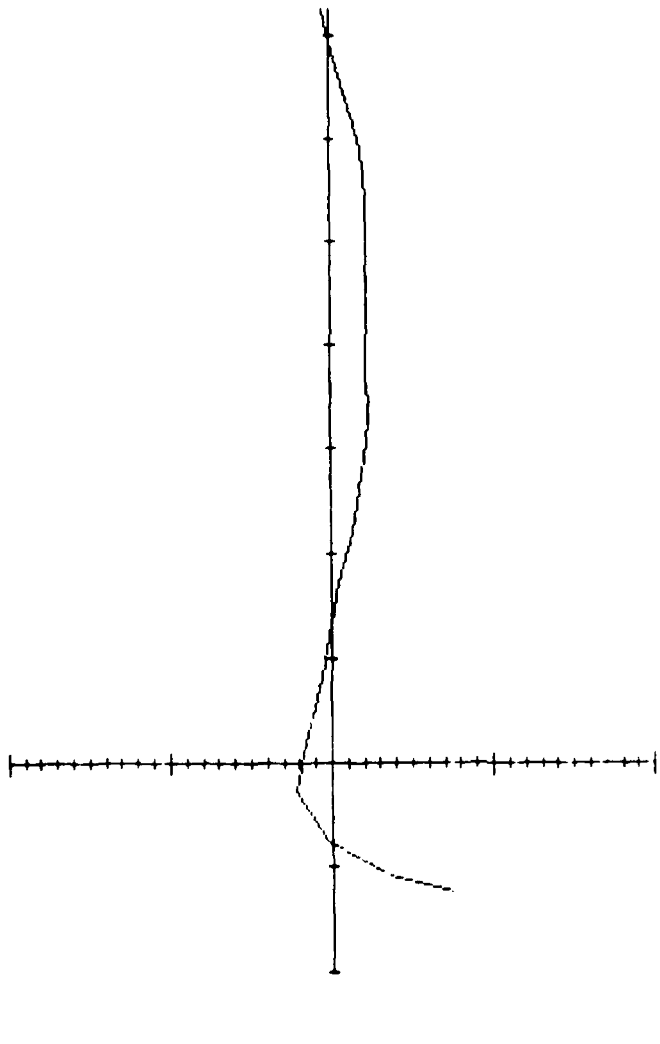
APPENDIX E

LORAN-C AND MINIRANGER RAW DATA PRINTOUT

```
The sample period=one sample every 12 Sec
REFERENCE STATION FILE =:AQUA
REFERENCE STATIONS:
    B  NEW                       709.871                  113.631
    C  PAULJ                     710.293                  112.46
LOCAL GRID ORIGIN:
       FOLLY BEACH               713.813                  94.377
RANGE BETWEEN STATIONS= 1.24471884375   ANGLE= 160.182067208
RANGE 1 CODE  2
RANGE 2 CODE  4
FROM POINT 1 TO POINT 2, COURSE= 143.4 , RANGE= .7
STARTING POINT-4.4    13.4
END POINT-4.0         17.9
HIT STRT WHEN READY
```

```
SAMPLE        W         X          Y            Z      Set     R1 ID    R2 ID     Time

            ( A       B       C )=  (A+B+C)          X / Y              AT     CT

   1        0.00        0.00  45564.05  60522.78  1    641.5  2  1353.5  4  03:04:03
   66.428  35.371  28.191 )= 180.000    -4.526   18.463   -.124  .075

   2        0.00        0.00  45563.98  60522.54  1    599.5  2  1330.0  4  03:04:14
 ( 68.711  34.624  26.665 )= 180.000    -4.434   18.493   -.107   .036

   3        0.00        0.00  45563.84  60522.22  1    556.0  2  1291.0  4  03:04:27
 ( 72.717  82.036  25.247 )= 180.000    -4.414   18.495   -.074  -.007

   4        0.00        0.00  45563.63  60522.06  1    532.0  2  1242.0  4  03:04:39
 ( 77.933  77.361  24.706 )= 180.000    -4.391   18.468   -.027  -.021

   5        0.00        0.00  45563.38  60521.98  1    536.5  2  1195.5  4  03:04:51
 ( 82.487  72.216  25.298 )= 180.000    -4.367   18.427    .021  -.016

   6        0.00        0.00  45563.24  60522.02  1    547.5  2  1148.0  4  03:05:03
 ( 86.884  67.053  26.053 )= 180.000    -4.344   18.382    .070  -.008

FECEIVED WRONG CODES:      Z1 = 561 Z2 = 2          Z3 = 561 Z4 = 2

   7        0.00        0.00  45562.83  60522.05  1    580.0  2  1048.0  4  03:05:27
 ( 95.306  57.050  27.644 )= 180.000    -4.293   18.292    .173   .005

   8        0.00        0.00  45562.68  60522.05  1    602.0  2  1003.5  4  03:05:38
 ( 98.563  52.865  28.571 )= 180.000    -4.270   18.249    .221   .012

   9        0.00        0.00  45562.52  60522.05  1    629.0  2   951.0  4  03:05:51
 ( 102.027  48.353  29.620 )= 180.000    -4.242   18.201    .276   .013

  10        0.00        0.00  45562.38  60522.00  1    655.5  2   903.5  4  03:06:02
 ( 104.838  44.560  30.601 )= 180.000    -4.216   18.159    .326   .023

  11        0.00        0.00  45562.18  60521.97  1    683.0  2   850.0  4  03:06:15
 ( 108.080  40.479  31.441 )= 180.000    -4.183   18.115    .381   .023

RECEIVED WRONG CODES:      Z1 = 797 Z2 = 4          Z3 = 798 Z4 = 4

  12        0.00        0.00  45561.80  60521.86  1    745.5  2   748.0  4  03:06:39
 ( 112.904  33.612  33.484 )= 180.000    -4.120   18.030    .487   .023

  13        0.00        0.00  45561.59  60521.82  1    780.0  2   697.5  4  03:06:51
 ( 114.685  30.603  34.707 )= 180.000    -4.018   17.985    .539   .022

  14        0.00        0.00  45561.44  60521.73  1    813.0  2   649.0  4  03:07:02
```

```
( 116.275  27.874  35.851 )= 180.000   -4.056 / 17.949    .590   .020

 15        0.00       0.00  45561.03  60521.56  1    877.0  2   545.5  4  03:07:27
( 120.292  22.235  37.472 )= 180.000   -3.979 / 17.878    .640   .000

 16        0.00       0.00  45560.87  60521.43  1    912.5  2   495.0  4  03:07:39
( 121.473  19.827  38.701 )= 180.000   -3.942 / 17.842    .744  -.007

 17        0.00       0.00  45560.66  60521.36  1    950.0  2   445.0  4  03:07:51
( 122.060  17.637  40.303 )= 180.000   -3.906 / 17.805    .795  -.015

 18        0.00       0.00  45560.46  60521.35  1    993.0  2   401.5  4  03:08:03
( 120.281  16.174  43.545 )= 180.000   -3.879 / 17.763    .845  -.011

                                                       Stop time  06:08:03:08:05
```



	<TDW>	<TDX>	<TDY>	<TDZ>
CUMULATIVE AVERAGE	0.000	0.000	45562.366	60521.931
STANDARD DEVIATION	0.000	0.000	1.148	.362

	<WX>	<WY>	<WZ>
CORRELATION COEFFICENT	9.99999999999E+99	9.99999999999E+99	9.99999999999E+99
REGRESSION LINE SLOPE	9.99999999999E+99	9.99999999999E+99	9.99999999999E+99
RESIDUAL	0.000	0.000	0.000
INDEPENDENT VARIABLE	1	2	2

	<XY>	<XZ>	<YZ>
CORRELATION COEFFICENT	9.99999999999E+99	9.99999999999E+99	.919
REGRESSION LINE SLOPE	9.99999999999E+99	9.99999999999E+99	.290
RESIDUAL	0.000	0.000	.143
INDEPENDENT VARIABLE	2	2	1

SAMPLES= 13

```
Set= 1
FILE NAME=C1011B
SAMPLES=  13
Set 1 stored
Storage done
```

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